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Development of an indicator of footpath erosion in Warwickshire using Plantain (Plantago spp)

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ABSTRACT

The control of erosion has long been a problem for land managers. With limited budgets the need for a cost-effective method that can estimate the vulnerability of the soil to erosion has never been greater. With its accepted ability to withstand high levels of compaction, this study investigates the possibility of using changes in *Plantago* cover as an indicator of the early stages of the breakdown in soil structure, an established precursor of erosion.

The study was carried out along a 1.34 km stretch of pathway, which runs over an improved grassland meadow south of the City of Coventry, England during a 346 day period from mid September 2006 to August 2007. Samples were taken during the winter (November 2006 – January 2007) and summer (August 2007). Three sections were identified representing high, low and intermediate use and thirty transects were set up across the path in each section, each with four quadrats. Vegetation cover and soil samples were taken from each quadrat.

Season was seen to have a marked influence on *Plantago* cover indicating the iteroparous nature of *Plantago* and hence its limitations as an indicator. During the summer, no significant relationship was identified between soil compaction and *Plantago*, although a significant (P<0.001) negative correlation was identified between *Plantago* and user numbers along the centre of the path. Along the transect *Plantago* cover was significantly (P<0.05) greater in the transition zone (either side of the centre of the path) where trampling was less. Thus, although, it would appear that *Plantago* has its limitations as an indicator of compaction, its presence does appear to be related to the level of trampling as part of a threshold effect. Under light trampling *Plantago* is largely absent as it appears to be out competed by more competitive grass species, while under heavy trampling it is also absent due to the abrasive action of footfalls. Given that trampling is strongly related to compaction, the increasing presence of *Plantago* in the sward may therefore provide an early warning of potential soil erosion.

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CHAPTER 1: INTRODUCTION

1.1 Background

The last two decades has seen a marked rise in the numbers of people participating in walking/rambling either in organised groups or as individuals. From 1987 to 2007 the Ramblers Association saw an increase in membership from 40,000 to 140,000 (Ramblers Association 2007). The increased interest in walking as a leisure activity is reflected in figures released by StarUK (2007) who reported a rise of 4.4 million in visitors to the countryside for walking between 2000 and 2003. According to Edwards (1991) this escalation in demand is the result of more leisure time, more disposable income and increased accessibility to sites and areas of interest. This increase in demand has significant ecological, social, managerial and economic impacts (Jewell and Hammitt 2000, Pratt 1996).

The walking/rambling industry in England generates £2 billion and supports up to 245,000 full time jobs (Christie and Matthews 2003 in Ramblers Association 2007). Sharpley and Craven (2001) suggest that tourism has replaced agriculture as the mainstay of the local rural economy. However, the economic impact can also be negative according to Evans (1996) who, using data from local authorities, estimated that footpath erosion cost UK agriculture £1.19 million in lost soil. Others suggest that these costs are indirect rather than direct, as finance allocated to erosion control is limited by available budget rather than demand (Lake District National Parks Authority 2007, M. Fry personal communication 2007). Kozlowski (1999) suggests that not only greater demand but higher labour and material costs will add to the pressure on recreational professionals to find alternative methods of managing these impacts. Early detection of these problems can substantially reduce the amount and therefore the cost of any remedial work (Lake District National Parks Authority 2007).

However, an ongoing issue faced by countryside managers according to the Lake District National Parks Authority (2007) is that it is easier to find funding to tackle a major erosion problem which has already occurred than to cover the costs of routine maintenance or preventative work. Dorren *et al* (2004) contend that this is a result of a misleading assumption that soil lost through erosion is replaceable, while in fact soil erosion (the loss of fertile top soil) is irreversible, at least in the short term.

1.2 The ecological impacts of trampling on soil and vegetation

Trampling has three main effects on the natural soil substrate: abrasion of vegetation, abrasion of organic soil horizons and compaction of soil (Cole 2003) as illustrated in Figure 1.1. Also, when discussing the impact of trampling, it is important to discriminate between the effect of trampling as a whole and that of compaction, which as suggested by Carignan and Villard (2001), are often difficult to separate.

Figure 1.1 has been removed for reasons relating to copyright compliance

Figure 1.1 The interaction of the three main impacts caused by trampling (taken from Cole 2004).

Kuss (1986) states that the type and texture of soil will determine moisture and drainage properties, amount of aeration, and the nutrient levels available to the plants of the habitat. These in turn will influence how a plant may respond to trampling (Kuss 1986). Trampling on mineral soils causes compaction, which in turn causes increased bulk density, decreased macropore space, and increased soil penetration resistance (Chappell *et al.* 1971, Roovers, Baeten and Hermy 2004). Factors most commonly influenced by change in soil density are: (a) drainage properties and moisture relationships in the root zone, (b) soil porosity and aeration, and (c) availability of soil nutrients (Liddle 1997). Moreover, compaction has been shown to result in a breakdown in soil structure, an established precursor of soil erosion (Chappell *et al* 1971, Kozlowski, 1999).

1.2.1 Soil

Studies have demonstrated a clear relationship between soil compaction and human activity and the influence this has on soil erosion and plant growth (Kozlowski 1999). According to Cole (2003) the mechanisms of erosion can be broken down into two processes the detachment of soil particles and the transport of dislodged particles.

However, there appears to be some debate as to the role of recreational activities in the erosion process. Quinn, Morgan, and Smith (1980) in their studies on the effects of human trampling on soil erosion, suggest that the action of walking both detaches soil particles (the first stage of erosion) and transports them (the second stage of erosion). This view is shared by Liddle (1997) who suggests that the shearing action of the toe both detaches and transports soil particles. However, other commentators such as Cole (2003) suggest that the action of walkers merely loosens soil particles, and this provides the conditions in which agents of erosion such as wind and water can operate more effectively.

Nevertheless, there seems to be agreement that the key influence of trampling on the erosion process is the removal of vegetation cover and the breakdown in soil structure. There would, however, appear to be a difference in opinion as to when the process of erosion starts. Elwell and Stocking (1976) suggest that soil erosion does not start until at least 30% of the ground is bare. However, this theory is contradicted by Liddle (1997) who used 50% as the critical point. Weaver and Dale (1978) in their study of meadows in the Rocky Mountains (USA) suggested that 1000 passes by walkers are needed to reduce vegetation cover to that critical point of 50%, while data collected from a sand dune pasture in Wales (Liddle 1997) suggested 1445 (a mean of both winter and summer measurements).

The requirement for bare ground as a precursor to erosion is questioned by Chappell *et al.* (1971) and Quinn, Morgan, and Smith (1980) who suggest that soil breakdown occurs while vegetal wear is still occurring. These authors also suggest that high levels of soil breakdown occur at the early stage of path creation and level off as the ground adapts to the new regime. This levelling of the compaction, as indicated by bulk density, can be due to the rearrangement of the clay particles (Harris 1971 in Liddle 1997). Studies in Washington D. C. USA, have recorded increases in bulk density from 1.60 g cm^{-3} to 2.20 g cm^{-3} as a result of compaction (Kozlowski 1999). Such high measurements tend to be pronounced in the top 5 cm of the soil profile with the greatest impact being in the top 2.5 cm (Ziegler, Sutherland and Giambelluca 2001).

According to Kozlowski (1999) the main implications of soil compaction are reduction in porosity (particularly the volume of macropores), increase in the mechanical strength of the soil, impedance of infiltration rates and changes in water content and transmission rate in the soil. The degree of soil compaction depends largely on soil texture, clay particle thickness, water content and the presence of organic matter (Singer and Munns 1999).

Cole (1982) in his study on the impact on Wilderness Campsites in Montana, USA, reported that infiltration rates decreased by 30%. However, a study in the rainforests of north east Australia reported a reduction in infiltration of 90% at a bulk density of 0.51g cm^{-3} (Talbot, Graham and Turton 2003). A study by Warkentin (1971) in Liddle 1997), in Natal, South Africa suggested that a bulk density of between 1.1 and 1.5 g cm^{-3}, had little influence on infiltration rates, although at higher bulk density, infiltration rate was affected. This reduction in infiltration rates can be the result of crusting/sealing of the soil surface, a common result of trampling (Singer and Munns 1999, Fox, Bryan and Fox 2004). In addition to crusting, Ohu, Folorunso and Adeniji (1989) and Huang, Onyang and Zhang (2006) suggest that the increase in the proportion of micropores in the surface layers of the soil, increases surface tension preventing movement of the water down through the soil horizons. This has implications for plant growth, as it restricts the movement of nutrients through the soil to the plant via mass flow (Kozlowski 1999).

Soil texture dictates the susceptibility of soil to compaction. Coarse-textured soils (>2 mm) which contain few pore spaces suffer less from compaction as the particles are resistant to movement under pressure. However, fine-textured soils (<2 mm) are more prone to compaction and water logging due to the shape and alignment of the clay particles. The relationship between compaction and water content lies in the fact that water cannot be compressed (Singer and Munns 1999). The pressure increases bulk density in the first instance, then as water content rises, bulk density increase slows, ceases altogether and then declines (Crawford and Liddle 1977, Raper 2005).

In addition to its impact on soil hydrology, compaction influences soil aeration, as it decreases the proportion of free draining macropore space and increases the proportion of micropore space (Willatt and Pullar 1983, Huang, Lacey and Ryan 1996). In non-compacted soil, oxygen (O_2) which is consumed during root respiration and microbial activity is replaced by diffusion from the atmosphere, and carbon dioxide (CO_2) is lost by the same process (Zainol *et al.* 1991). With the loss of macropore space this exchange of gases is reduced, with the result that the soil O_2 concentration can decrease and CO_2 concentration increases by up to 20%. Work carried out by Watson and Kelsey (2006) into the impact of soil compaction on fine root density of *Quercus palustris* suggested that average O_2 diffusion rates (g/cm^2/min) in compacted soils fall from 0.32 to 0.16 and 0.13 to 0.07 at soil depths of 15 cm and 30 cm respectively. Stolzy and Letey (1964) suggest that the roots of many plants will not grow with oxygen diffusion rates below 0.20 g/cm^2/min.

Chappell *et al*. (1971) suggest that compaction not only leads to high CO_2 concentration but also high methane (CH_4) and nitrous oxide (N_2O) levels. Several reports indicate that an air-filled porosity of 10% (v/v) represents the critical limit of soil aeration and rootability, respectively (Houlbrooke *et al.* 1997). In addition to changes in aeration and water concentration, compaction also changes soil chemistry (Chappell *et al*. 1971). Observations have suggested increases in ammonium, reduced nitrate ion concentrations, increased amounts of ferrous iron, reduced pH and increased phosphate solubility (Kozlowski 1999).

1.2.2 Changes in vegetation

The impact of walking/trampling on plant communities has been studied intensively over the last four decades (e.g. Burden and Randerson 1972, Cole 1982, Kozlowski 1999, Roovers, Baeten and Hermy 2004). Trampling has both a direct and indirect effect on vegetation. Direct effects include damage to plant tissue, whereas indirect effects include damage to the root ecosystem through compaction (Chappell *et al.* 1971, Cole 2003). As mentioned above, compaction can alter the availability of water and mineral nutrients, creates an anaerobic environment and increase the mechanical strength of the soil, impeding root growth (Liddle 1997, Kozlowski 1999, Cole 2003).

1.2.2.1 The general response of plants to disturbance

Liddle (1997) suggests that the human plant interaction has three stages. The first is the *Alpha process* which starts with the decision of the human to either move away from the plant or make contact with it. This initiates the *Beta process* when the human makes contact with the plant and finishes when the contact is broken. How the plant responds to the beta process is termed the *Gamma process* (e.g. death or tolerance). The degree to which a plant tolerates this pressure is a combination of its ability to resist the initial disturbance of trampling and its subsequent capacity for re-growth (Cole 1995). Cole (1995) expresses this in terms of three indices resistance, resilience and tolerance. Liddle (1997) suggests that plants do not have a trampling survival strategy, rather they have a certain combination of characteristics which enable them to survive. These characteristics manifest themselves through either a high level of resistance or high recovery rates, with the exception of sedges (*Carex* spp.), which appear to have both high resistance and good recovery rates. Roovers, Baeten and Hermy (2004) state that the capacity of species to resist trampling is strongly associated with life forms and plant strategies. Grime (2001) identified three primary strategies for survival in different environmental conditions. Ruderal strategists (r- selected species) occur in favourable, disturbed environments, competitive strategists (k- selected species) prefer favourable, undisturbed environments while stress tolerant plants are found in unfavourable, but undisturbed habitats (Fitter and Hay 1995, Grime 2001). Research by Hirst *et al.* (2003) shows that after disturbance, ruderal species that have the potential for rapid growth, devote a large proportion of their resources to reproduction and growth and tend to colonise these disturbed areas. However, as a consequence they are generally short lived annuals devoting few resources to defence. These species have high resistance to environmental stress (trampling and compaction), but low competitive ability (Noe and Blom 1981).

Liddle (1997) has suggested that this dominance of ruderal species is transient, as although they have the ability for quick growth (resilience), they have few attributes for tolerance or resistance. Ikeda and Okutomi (1990) suggest that at low trampling levels pioneer species become dominant. However, heavy trampling markedly suppresses the competitive abilities of pioneer species, favouring the establishment of tread community species. This dominance is only lost when trampling intensifies and the narrow-leaved species re-colonise due to their faster recovery rate (Ikeda and Okutomi 1990, Liddle 1997).

Survival in the trample zone is also a function of *life form* as well as strategy. Life form is a method of grouping plant species according to their morphology. The system in most common usage, according to Liddle (1997) is that of Raunkier (1934) based on the position of the vegetative buds or persistent stem apex. Cole (1995) recognised that plants with perennating buds at or below the soil surface (hemicryptophytes and cryptophytes) are more resistant than chamaephytes (plants with perennating buds above the soil surface).

1.2.2.2 The response of roots to trampling and compaction

The ability of a plant to grow roots is dependent on the plant's ability to produce sufficient carbohydrate (Liddle 1997). Kozlowski (1999) states that compaction can increase mechanical resistance and alter the availability of water, mineral nutrients and O_2, creating hypoxic conditions in the rhizosphere. The primary influence of mechanical impedance is to create conditions which limit the ability of roots to penetrate pore spaces and to expand once penetrated (Engelaar, Visser and Veen 1995). Liddle (1997) states that although the level of compaction differs with soil type, in general a bulk density of 1.8 g cm^{-3} is the maximum threshold beyond which plant roots cannot function.

A frequent response of plants to stressful conditions is to allocate a large proportion of their photosynthate to the root system (Liddle 1997). Different stresses produce different solutions. In arid conditions resources are allocated to the elongation of roots and the growth of root hairs to forage for water (Fitter and Hay 1995). In toxic soils, Fitter and Hay (1995) suggest that many plants allocate resources to developing storage organs, as opposed to roots. However, in compacted soils, where the increased mechanical strength of the soil inhibits root penetration, a reduction in elongation is accompanied by an increase in the diameter of roots, giving them greater resistance (Warwick 1980, Engelaar and Blom, 1995). Pritchard (1994) states that this thickening of the roots is caused by an increase in the diameter in the cell through thickening of the cell wall. Striker *et al.* (2007) demonstrate that root strengthening is a trade off against growth, a view shared by Whitfield, Davison and Ashden (1996) who suggest that root restriction is associated with reduced leaf growth. Pritchard (1994) suggests that an increase in soil bulk density from 1.6 to 1.8 mg m^3 reduces root growth rate by some 30 %.

Kozlowski (1999) suggests that compaction also directly influences the movement of nutrients by mass flow and diffusion. Phosphorus (P) for example is one of six essential macronutrients (N, P, K, Ca, Mg and S) and is acquired by the plant in the form of phosphate from the soil solution (soil water) (Hammond, Broadley, and White 2004). As concentration of P in the soil solution is often low, the supply of P to the root surface is slow (Fitter and Hay 1995). Hence, P is one of the most unavailable and inaccessible macronutrients in the soil and frequently limits plant growth particularly in roots (Hammond, Broadley, and White 2004). However, Engelaar, Visser, and Veen (1995) suggest that this reduced uptake of P from soil solution may be compensated for by the fact that compaction increases the mass of soil in the root zone thus allowing uptake of P through direct contact of the root with the soil.

Compaction also inhibits root growth through reduced oxygen supply. A soil bulk density of more than 1.6 g cm^{-3} at oxygen levels up 20% will inhibit root growth (Lotz 1990).

1.2.2.3. The response of stems, leaves and flowers to trampling and compaction

Trampling has a direct effect on above ground tissue, bruising, crushing, shearing off and even uprooting plants. The *Beta process* reduces plant height, stem length, leaf area and seed production, (Cole 1982, Liddle 1997, Kozlowski 1999, Roovers, Baeten, and Hermy 2004). The reduction in height and leaf area decreases the photosynthetic ability of plants, resulting in depleted carbohydrate reserves (Cole 2003). Reduction of the rate of photosynthesis can be attributed to;

- The direct shearing off of leaf area resulting from the act of trampling (Cole 2003).
- Mechanical impedance (compaction) of roots, resulting in a slowdown of leaf appearance (Tubeileh *et al.* 2003).
- Increased compaction of the soil, which inhibits water movement leading to a reduction of leaf and root xylem potential (Fitter and Hay 1995), in response to which the plant closes its stomata thus reducing its carbon assimilation rate (Tubeileh *et al.* 2003).
- Availability of mineral nutrients (Kozlowski 1999).

Soil compaction can often lead to an anaerobic state developing in the soil. In the absence of sufficient oxygen, essential root function is not maintained, particularly the uptake of minerals such as P and K, affecting the maintenance of cell membranes and their synthesis (Kozlowski, 1999).

The ability of plant communities to survive in a trampled environment depends largely on the capacity of that species to reproduce (Pino, Sans and Masalles 2002). Harper (1967) suggested that colonizing species of plants would have higher reproductive efforts than plants of mature habitats. This requires the allocation of resources to growth and reproductive organs (Grime, 2001). The timing of reproduction varies between annual (semelparous) and perennial (iteroparous) species and is influenced by both ecological and evolutionary factors (Pino, Sans, and Masalles 2002). In order to overcome the problems associated with reproduction, plants that survive in compacted soil conditions tend to adopt an r- selection strategy (Whinam and Chilcott 2003, Godefroid and Koedam 2004).

1.2.2.4 The impact of trampling on *Plantago major*

Perennial species of *Plantago* have larger leaf areas than the annual species of *Plantago.* This larger vegetative size allows the perennial species to produce greater weights of seed per plant than the annual species. Of the perennial species examined by Primack (1979), four species are confined to natural vegetation while two species: *P. rugelii* and *Plantago major*, are found characteristically in disturbed areas. These two weedy species have higher mean reproductive output values in general than do the other perennial species (Primack 1979).

Liddle (1997) suggests that, judging by its worldwide distribution, Greater Plantain (*Plantago major)* a perennial weed, demonstrates many of the qualities needed to survive the stresses induced by trampling. Lotz (1990) suggests that within *Plantago major* two subspecies have been identified each with different characteristics, ssp *pleiosperma* and ssp *major*. Within ssp *major* there are two ecotypes one capable of resisting trampling and the other capable of withstanding mowing or grazing. This view is supported by Liddle (1997) who proposes that as well as its hemicryptophyte life form, the success of *Plantago major* ssp *major* under trampled conditions may be a result of its general features of flexible leaves, and its capacity for self-fertilisation or cross fertilisation (Lotz 1990) within its own genotype.

Interestingly, Warwick (1980) suggests that a certain level of vegetation cover offers *Plantago major* an element of cushioning and protection from the direct effect of trampling (abrasion of vegetation). This same pattern of preference for areas with some cover was identified by Klecka (1937) in his studies in Czechoslovakia, as reported in Liddle (1997). This is corroborated by Chappell *et al.* (1971) in their study of the effect of trampling on the chalk downlands of Hampshire UK, who observed that *Plantago* (in this case *Plantago lanceolata),* was more frequent in the intermediate zones, areas with short swards up to 5 cm. In taller swards Engelaar and Blom (1995) noted that *Plantago major* loses out to more competitive species for light.

Plantago major has the ability to behave as an 'r' strategist (Liddle 1997). This is supported by Warwick and Briggs (1980), who observed that prostrate plants devoted a statistically significantly greater percentage of dry weight to reproduction. Engelaar and

Blom (1995) noted that as a result of its short life cycle *Plantago major* ssp *major*, produced vast numbers of seeds. This view is shared by Primack (1979) who demonstrated that *Plantago rugelii* and *Plantago major*, both characteristic of disturbed areas, produced three times as many seeds as other perennial species, however the offspring have a relatively low probability of surviving to adulthood, a typical 'r' strategist characteristic. Furthermore, the presence of bare ground is fundamental in creating conditions suitable for seed germination (Hirst *et al* 2003). The control of sward height after germination is important to ensure that the surviving seedlings are not out-competed for resources (Blom 1979). One of the key impacts of trampling (soil compaction) is a reduction in the availability of phosphorus. However, *Plantago major* demonstrates high survival even at low phosphorus levels suggesting that it has the ability to regulate its demand for phosphorus (Lotz 1990).

Engelaar, Jacobs and Blom (1995) have highlighted the ability of the *Plantago major* root system to survive in compacted soils. Dijkstra and Lambers (1989) suggest that this ability to survive the mechanical stresses of compaction is the result of a higher amount of cell wall material (sclerenchyma). In a series of experiments Engelaar and Blom (1995) demonstrated the difference in the ability of the root system of common sorrel (*Rumex acetosa)* and greater plantain *Plantago major* to spread in compacted soil. The results indicated that root the system of *Plantago major* had a superior ability to survive under conditions of trampling.

Engelaar and Blom (1995), Primack (1979) and others have clearly demonstrated *Plantago major's* ability to adapt both its reproductive strategy and physiology to suit the prevailing environmental conditions, indeed Liddle (1997) suggests even uniquely so. This underlines its potential as an indicator species of trampled zones (Burden and Randerson 1972). This view is shared by Ignatieva and Konechnaya (2004), whose research into the plant communities of 18 parks in St Petersburg, Russia, identified *Plantago major* as an important indicator species of disturbed ground.

2.1.3 Indicators and their role

The use of indicator species for assessing environmental condition appeals to many land managers as it can provide a time and cost-efficient tool to assess the impacts of environmental change (Cousins and Lindborg 2004). Indicators should be cost-effective to measure and able to be accurately estimated by all personnel (even non-specialists) involved in the monitoring (Carignan and Villard 2001, Cousins and Lindborg 2004).

Ecological indicators have several purposes (Fanelli, Tescarollo and Testi 2006):-

1) They can be used to assess the condition of the environment
2) Monitor trends over time or to provide early signals of changes
3) They can be used to detect and summarize the relationships between plants and habitat factors such as soil, climate and disturbance.

In order to perform these functions a good indicator species should reveal evidence for impacts of environmental change (Cousins and Lindborg 2004). For this purpose the chosen species has to be sensitive to the level, frequency or intensity of any change e.g. grazing, fire, flooding or competition (Cousins and Lindborg 2004). Godefroid and Koedam (2003) suggest that there are two very different concepts of indicator species. One is as a species, the presence or absence of which, indicates some environmental condition e.g. acidity or compaction. This view is shared by Liddle (1997), who suggests the concept of decreasers, increasers and invading species which can have both negative and positive associations with human disturbance (Carignan and Villard 2001). The second concept involves those species, which can provide an indication of the 'biodiversity' value of habitats.

Whichever concept is required it is important to identify what is trying to be measured, so that the appropriate indicator species can be chosen (Cousins and Lindborg 2004). It has long been recognised that certain species are indicators of habitat characteristics e.g. ling (*Calluna vulgaris)*, is an acid tolerant species whereas upright brome (*Bromus erectus)*, is an acid intolerant species (Fanelli, Tescarollo and Testi 2006). Hence, certain species with a strong association with a particular habitat characteristic can be useful indicators, if only a narrow range of ecological conditions are being investigated (Carignan and Villard 2001).

2.1.4 Aim and objectives

The overall aim of this study is to assess if abundance of *Plantago major* can be used as an indirect, rapid indication of footpath erosion in Warwickshire. Building on existing research, this aim will be investigated by drawing on key relationships identified in Figure 1.1. On this basis it is hypothesised that trampling will lead to a reduction in vegetation cover, increased compaction of the soil and changes in species composition. These relationships will be examined using the following specific hypotheses:-

1 As footpath user levels increase there will be a reduction in the amount of vegetation present evidenced by an increase in the proportion of bare ground and a reduction in vegetation height.

2 The effects of this will not manifest themselves equally over all species. Species such as *Plantago major* will exhibit tolerance effects at low user levels.

3 As footpath user levels increase there will be an increase in soil compaction, evidence by increased soil bulk density values.

4 As soil bulk density increases there will be an increase in the proportion of *Plantago major* due to its greater resilience to compaction.

CHAPTER 2: MATERIALS AND METHODS

2.1 The study site

Located to the west of the town of Kenilworth, England (Figure 2.1) between grid references SP279721 to 268717, the study site forms part of public footpath K13 (Warwickshire County Council path numbering system) sections of which were incorporated into the Kenilworth Millennium Trail in 2000.

The Kenilworth Millennium Trail attracts over 20,000 visitors per year and runs for one and a half miles around what was once the perimeter of the old mews (an artificial lake) to the west of Kenilworth Castle.

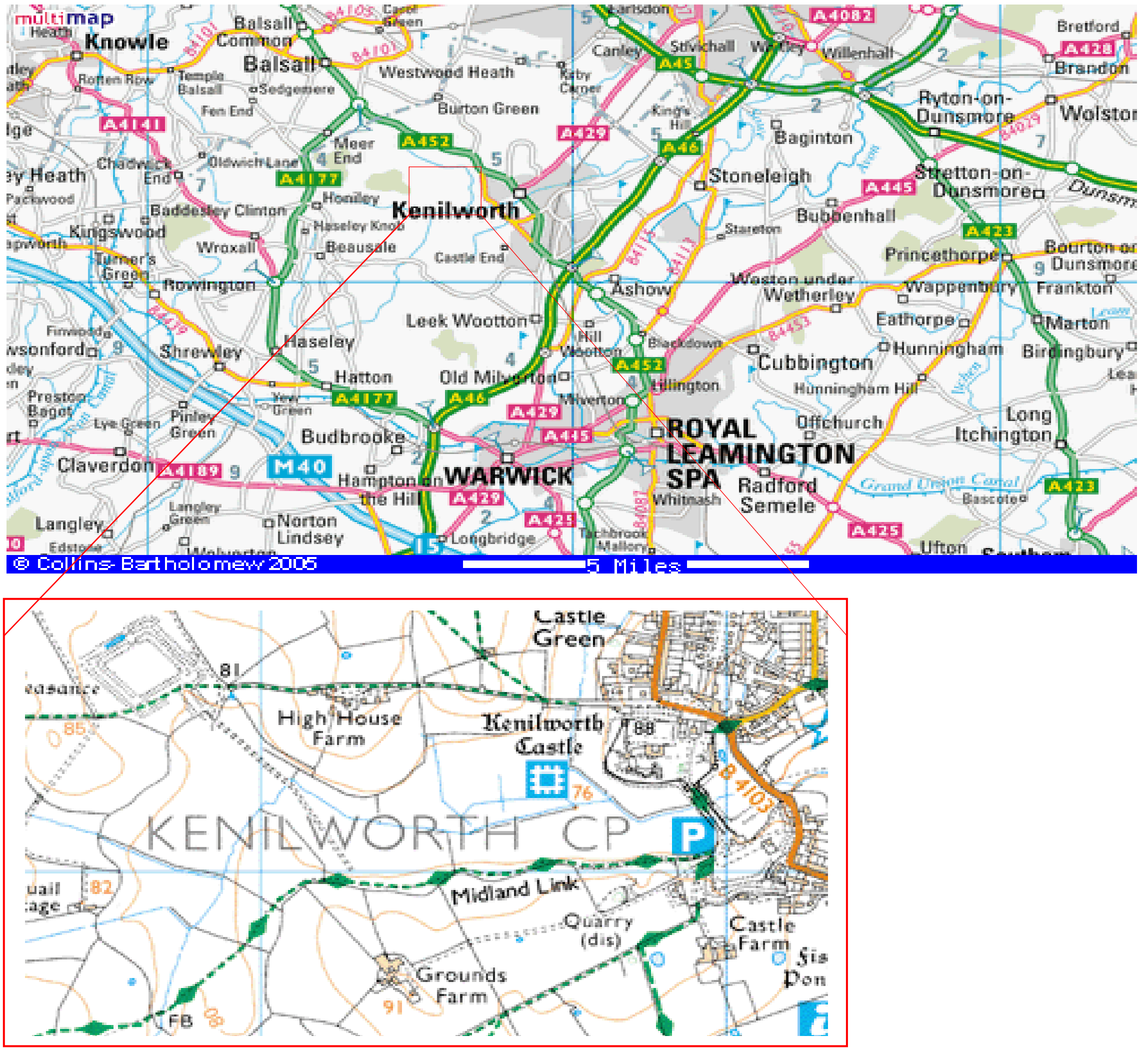


Figure 2.1 Location of Kenilworth Millennium Trail, Source: Multimap (2007).

The site was selected as it best fulfilled the requirements (1) consistent vegetation type, (see section 2.1.5), (2) uniform topography (i.e. little gradient) and was representative of typical improved and semi-improved neutral grasslands with a soil pH of 6.0 to 6.9. The site was also reasonably accessible from the University, the landowner was amenable to the surveys being carried out and the number of users could be gauged. The fact that the stretch of pathway studied had been under the control of an agri-environmental scheme for 3 years with no spraying or cultivation was also favourable in terms of limiting the factors which might affect indicator occurrence.

Conducting this study in Warwickshire was important as very few studies into footpath erosion have been undertaken in the lowlands/midlands, the majority of work being conducted in mountainous areas (Cole 2004) and concentrating mostly on sensitive habitats such as the heathland areas of the highlands and the chalk downlands of south and south -west England.

2.1.1 Climate

The site has a northern temperate climate, with mean daily temperatures of between 3^0C and 6^oC for November to January (the winter collection period) and between 11^0C and 20 ^{0}C during August (the summer collection period). The site was subject to well above average rainfall over both the collection periods (see Chapter 3 Section 3.1, Table 3.1 for details of rainfall).

2.1.2 Topography

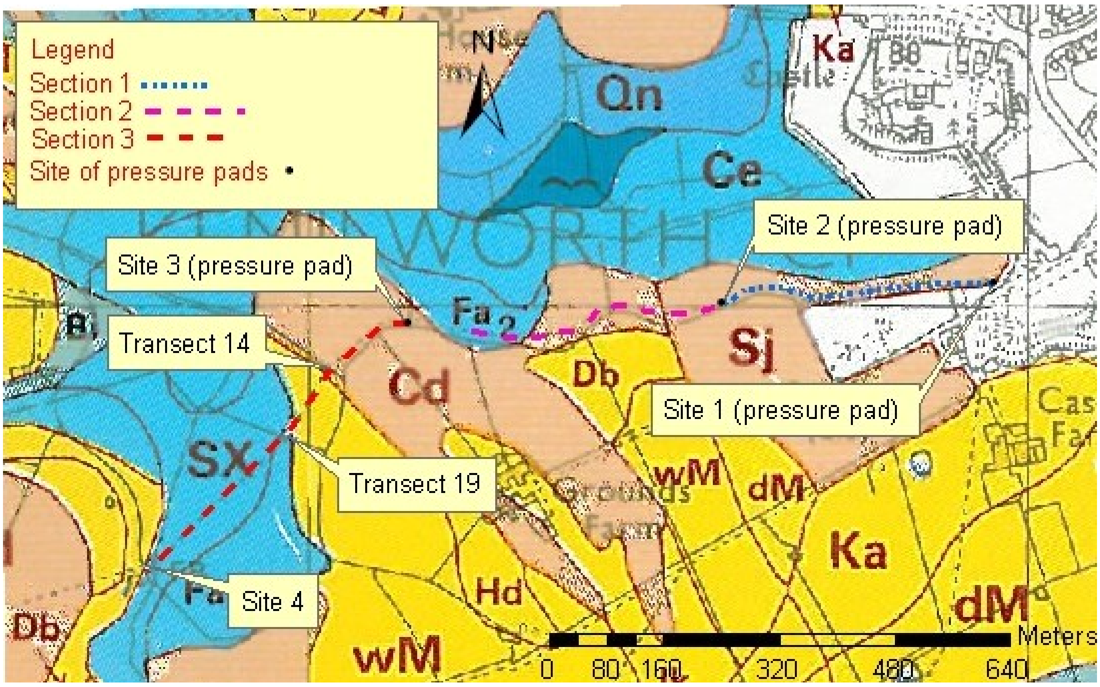
The path runs westward at an elevation of 82 m (asl) from site 1 to site 3. Here it bears south west dropping to 80 m at Site 4 (Figure 2.2). Section 1 is predominately north facing with a slight gradient, levelling off between Site 2 and Site 3, where it slopes gently to the south west. A mixed hedge of between 2 m to 10 m in height runs approximately 5 m south of section 1 for the first 367 m, where it retreats to 20 m, opening up into a pasture field for the full length of section 2. At Site 3 the hedge encroaches to within 2 m of the path for the first 150 m, then at transect 14 it opens up again into a hay meadow sloping gently to the south west until site 4, where it reaches Inchford Brook. At transect 19 the path runs over the remains of a removed hedge.

2.1.3 Underlying geology

From Site 1 the path runs over Carboniferous sandstone to Site 2 and from there over Triassic sandstone to Site 3. The first 150 m of section 3 lies over Triassic mudstone or clay shale after which the bedrock to Site 4 is glaciofluvial or river drift (Beard 1984).

2.1.4 Soils

The soils of sections 1 and 2 are predominately sandy loams, section 1 being dominated by Shifnal series and section 2 by Clive series. Shifnal is slightly coarser with a greater proportion of sand particles (72% to the 65% of the Clive series). In section 3 the first 130 m is dominated by Clive series, the next 80 m by Whimple series, a fine silty clay loam, while the last 280 m is of the Stixwould series, an alluvial clay loam (Beard 1984).



Key to Soil type

Sj	Shifnal; a medium sandy loam	Qn	Quorndon: Coarse sandy clay loam	dM	Dodmoor; Fine clay loam
Cd	Clive; a fine sandy loam	Ce	Compton; clay river alluvium	Ka	Kenilworth; Fine loamy or fine silty
wM	Whimple; a fine silty clay loam	Fa_2	Fladbury; Clay river alluvium	Hd	Hodnet; Fine loamy or fine silty
SX	Stixwould; an alluvial clay	Db	Dunnington Heath; Coarse clay loam	Ik	Inkberrow; Fine sandy loam
Bi	Brockhurst; Fine slit clay loam				

Figure 2.2 Soil types and their location along the route (adapted from Beard 1984)

2.1.5 Site vegetation

The stretch of path used in this study runs over improved and semi-improved neutral grassland dominated by perennial ryegrass *Lolium perenne,* and white clover *Trifolium repens.* This fits well with National Vegetation Classification (NVC), MG7 *Lolium perenne-Trifolium repens* (Rodwell 1995). Along the path edges and in gateways the vegetation community develops characteristics closer to MG7e *Lolio-Plantaginetun,* a *Lolium perenne* and *Trifolium repens* dominated sward with, *Plantago major* becoming more frequent (Rodwell 1995).

2.1.6 Site preparation

Following agreement from the landowner the path was surveyed and three levels of use were initially identified. These were subjective judgements based on simple aesthetic criteria. Stretches showing evidence of extensive compacted and cracked soil with little or no indication of living vegetation were classified as Section 1 (Roovers, Baeten, and Hermy 2004). Areas with reduced sward height, which showed signs of moderate soil surface disturbance were classified as Section 2 (Chappell *et al.* 1971). Section 3 was identified as the stretch with least use, based on the reduced height of the sward, little or no sign of soil disturbance and the fact that the route was off the main line of the Millennium Trail. In order to confirm these initial assessments a monitoring system was installed (for details refer to section 2.2.2). Sections 1, 2 and 3 were 381m, 379 and 577m in length respectively.

2.2 Experimental design

Three factors were examined in the study: (1) user levels, (2) plant % cover and (3) soil structure. This meant that the design of the experiment had to incorporate all of these variables. The method adopted in this study drew on methods used in several previous studies e.g. Burden and Randerson (1970), Chappell *et al.* (1971), Crawford and Liddle (1977) and Roovers, Baeten, and Hermy (2004), to make this study as comparable as possible and to ensure a sound design.

Reduction in vegetation cover will be expressed as percentage of bare ground/height of vegetation; soil compaction will be indicated by soil bulk density and changes in species composition by the proportion of percentage cover of *Plantago major* when compared to other species.

2.2.1 Sampling strategy

Thirty transects were randomly positioned transversely across each section of pathway. Random positioning was achieved by using the random selector function on the calculator then multiplying this by the length of the section. The location of each transect line was measured from a fixed point with a trundle wheel. Initially the location of each transect line was to be marked by a peg. However, due to the popularity of the trail this was deemed to be a possible trip hazard.

Based on the design used by Roovers, Baeten, and Hermy (2004), a 50 x 50 cm quadrat, subdivided into a 100 units of 5 x 5 cm, was placed at each of four sampling stations along each transect (n_{total}=120 per section). Quadrat 1 was placed in the centre of the path. In sections 2 and 3, where the path was less obvious, vegetation mean height was taken and its lowest point was judged to be the centre of the path (Figure 2.3). Vegetation mean height (cm) was measured by dropping a plexi circle (weight 3 g) of 30 cm diameter (Hirst *et al.* 2003) down a measuring stick (Roovers, Baeten, and Hermy 2004).

Quadrats 2 and 3 were placed either side of quadrat 1 at a distance of 1 m (in the so-called transition zone). The distance of 1 m from the outside of quadrat 1 (Figure 2.3) centre was used because vegetation heights taken along sections 2 and 3 at this distance demonstrated consistent variation in the sward height of 3 to 5 cm, a measurement which Chappell *et al.* (1971) used to identify intermediate levels of use. Furthermore, observations have shown that 1 m represents a distance outside the impact zone of two people walking together. Quadrat 4 was placed consistently on the same side 10 m from the centre of the path, in sections 1 and 2 to the north, in section 3 to the north-west (see map) and represented an undisturbed site which was used as a control (Roovers, Baeten, and Hermy 2004).

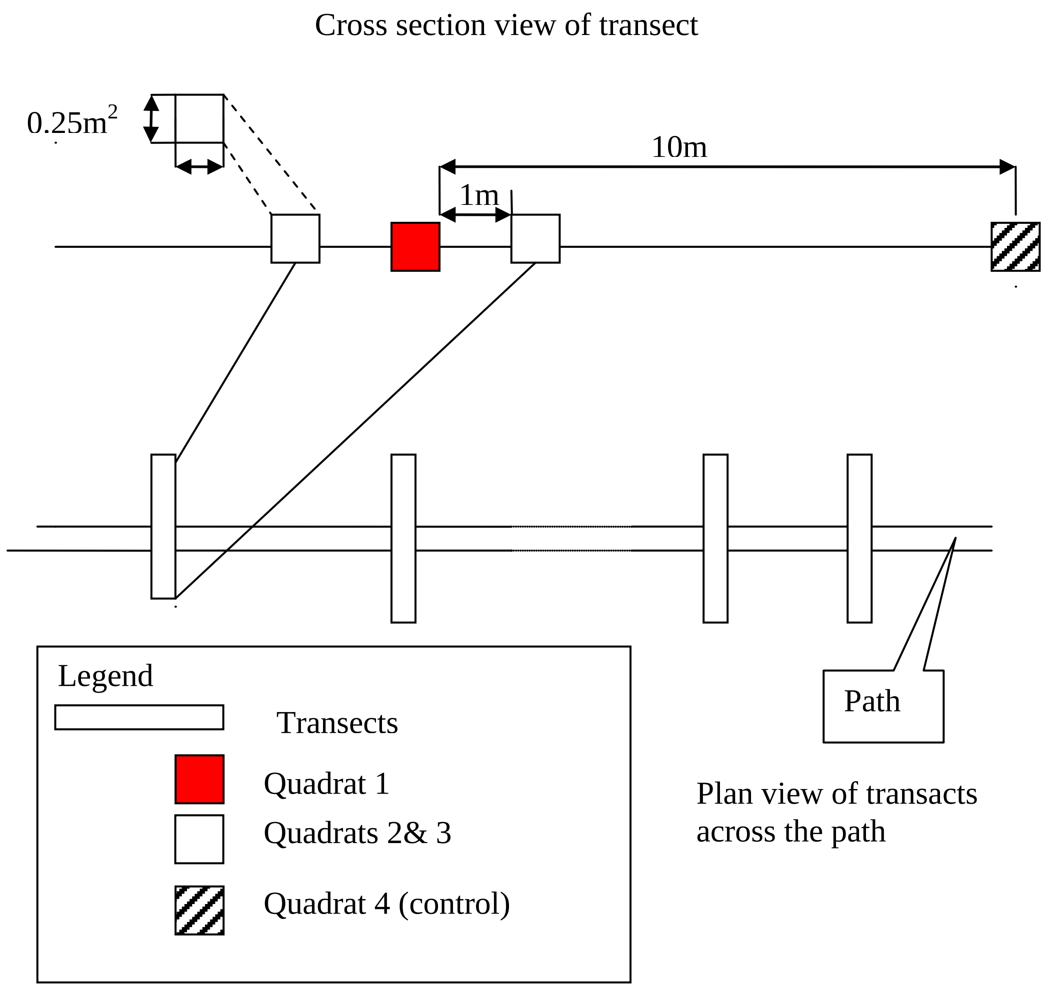


Figure 2.3 Layout of sampling method, showing plot measurements and position of quadrats in the transects across the path (adapted from Roovers, Baeten, and Hermy 2004)

2.2.2 Monitoring user levels

User levels were monitored using the Eco-Counter People Counters equipment and software, in conjunction with a M105 Handheld Palm data retrieval system. The Eco-counter consisted of a compressed air pressure pad (600 mm x 600 mm) which was buried as per the manufacturers' instructions at the access point of each of the three sections (see Figures 2.4, 2.5 & 2.6). Any hits on the pad are then transmitted through an underground wire to the receiver box, where the data were stored ready for collection using the handheld Palm device.

Figure 2.4 Site selection for pressure pads (Section 3)

Figure 2.5 Installation of pressure pads

Figure 2.6 Installation of receiver box

2.2.3 Collection of field samples (vegetation, soil, rainfall)

The abundance of plantain (*Plantago*) was determined by measuring vegetation cover, this was achieved by using a 50 x 50 cm (0.25 m^2) quadrat, subdivided into a 100 units of 5 x 5 cm.

The 0.25 m^2 quadrat was placed as indicated in Figure 2.3. *Plantago* cover was represented by its presence or absence in each square. Data were also collected on the percentage of bare ground and other flora e.g. grass species (G*ramineae*) and white clover *(Trifolium repens).* This was repeated for the four quadrats in each transect and at all 30 transects in each section (n_{total} = 12,000 per section)

Vegetation height was taken during the summer collection period, using a 30 cm diameter plexi disc dropped down a measuring stick from a height of approximately 40 cm, at 0.5 m intervals along a 10 m line, for all 30 transects in each section (n_{total} = 600 per section). This allowed for a profile to be constructed of the vegetation height giving some idea of the pattern of wear along Sections 1, 2 and 3.

Soil core samples were collected at the same time as the vegetation. To assess the extent of soil compaction in each of the three sections, a single measurement was collected from each of the quadrats using a 28 mm auger (Crawford and Liddle 1977). In line with work from Chappell *et al.* (1971) core samples were taken from a depth of 0-25mm (one measurement per quadrat) equalling $n_{total}=120$ per section. These cores were then extracted from the auger, placed in an air tight polythene bag, labelled and taken to the laboratory. Samples that were not processed within 2 days were placed in a freezer at -18 ^{o}C in order to retain moisture.

Rainfall data were collected on a daily basis from the weather station at Pleasance Farm. This was approximately 600 m from the study site and it was felt that this was close enough to provide a true reflection of local weather conditions at the study site.

2.3 Laboratory analysis

Laboratory analysis was conducted on the main soil parameters, namely bulk density and moisture content. Soil bulk density was used as the measure of soil compaction. Soil moisture content was calculated as part of the bulk density process (section 2.3.2).

2.3.1 Soil bulk density as a measure of soil compaction

There has been much debate over which is the most effective method of measuring soil compaction. The two recognised techniques are to either calculate bulk density of the soil or to use a penetrometer. Both methods have their own limitations, which should be recognised when using them. Penetrometers are susceptible to the influence of high water content in the soil which can lead to lower than expected resistance readings (Day 2000), making it imperative that the moisture content of each site be known (Liddle 1997). The penetrometer is easy to use, and many measurements can be taken quickly with an apparently high degree of accuracy (Liddle 1997) without disturbing the soil (Day 2000). However, Liddle (1997) suggests that there can be problems using the penetrometer when comparing different soil types, moisture contents and when comparing measurements taken by different users.

Day (2000) states that bulk density is excellent for comparing the degree of compaction of soils from different sites. For this study, considering the likelihood of high water content, especially in section 3, and that the research is concerned with comparing degree of compaction between sites with differing soil types, bulk density was deemed the most appropriate method for measuring compaction.

2.3.2 Determining soil bulk density

Once in the laboratory each soil auger sample was trimmed to 25 mm (removal of surface organic matter), then measured and cut, using a purpose-designed tool. Samples were then placed in a weighing tin, weighed and placed in the oven for 48 h at 105°C. Once cooled the samples were re-weighed. The following equation gave the bulk density:-

$$\text{Bulk density (g m}^{-3}\text{)} = \frac{\text{weight of oven dried soil}}{\text{volume}}$$

Volume of each soil sample was determined using the following formula:-

Volume = π r^2x depth (2.5 cm)

Moisture content was determined as part of the bulk density process, as the difference between wet weight and the oven-dry weight of the soil. :-

Moisture content (g) = weight of wet soil (g) - weight of oven dried soil (g)

2.4 Statistical analysis

Statistical analysis was conducted using the Microsoft Excel 2007 spreadsheet package.

2.4.1 Descriptive statistics

Counts of visitor numbers are presented in the results along with mean percentage cover values for vegetation and the soil bulk density profile across the path, for different user levels and also between seasons. Standard error was used to indicate the amount of variation around the mean. The coefficient of the variance (CV) was calculated for rainfall data as a measure of the variability between years.

2.4.2 Inferential statistics

Two-way ANOVA (P= <0.05) was used to investigate the relationship between position across the path and soil bulk density for different path sections and seasons. Least significant difference (LSD) (P=<0.05) was used to identify where exactly mean soil bulk density differed significantly between quadrats. Correlation analysis was used to identify the strength of any statistical association, between the different continuous variables.

CHAPTER 3: RESULTS

3.1. Rainfall data

Rainfall data were obtained from the local rain gauge located at Pleasance Farm. The total rainfall figures for each month during which this study was conducted (October 2006 to August 2007) are presented in Table 3.1, with monthly total rainfall figures for the proceeding 6 years from Pleasance Farm for comparison.

Overall mean rainfall data was 757 mm (2000-2007) and showed relatively little variation between years (CV = 18%). However, over the study period, there did appear to be a change in the monthly pattern of rainfall, with the greatest amounts falling during June and July (2007) where in previous years the largest amount has fallen between September and December. In fact the study period was subject to some of the greatest extremes of rainfall over this 8 year period, the lowest being in April 2007 with only 5 mm, while June and July 2007 saw the heaviest rainfall with 165 mm and 144 mm respectively.

Table 3.1 Total monthly rainfall (mm) for the study period October 2006 to August 2007, with totals for the previous 6 years for comparison. Data taken from the weather station at Pleasance Farm, Kenilworth.

	Year							
Month	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Jan	26.75	54	67	60	88	16.25	15	73.5
Feb	66.75	83.50	93.5	20	21	44.5	29.5	98.25
March	20	82.50	36	35	40	45.5	62	63.5
April	136	104.75	41.5	37	75.5	37	26.75	5
May	92	47.50	85.5	65.25	52.5	44	99	99
June	32.50	60	43.5	54.75	43	83	14.75	165.5
July	36	94.75	59.5	43.25	67.5	45	78.5	144.5
August	60.25	36	49.75	27.5	119	44.5	66.5	40.25
Sept	116	49	19	24.75	54.5	42	111	31
Oct	120.50	104	122.5	48.75	112	80	90.5	40
Nov	117.75	52	108.5	58	35.5	61.5	75.5	54.5
Dec	122.50	23	102	68	27	47.5	83.5	60
Total	947.0	791.0	828.3	542.3	735.5	590.8	752.5	875

3.2 Visitor numbers

A total of 19,914 people was recorded using the Millennium Trail at the main access point (Site 1) over the surveyed period from 1st October 2006 to 30th August 2007. These data are summarised in Figure 3.1. The finding of the foot pad monitoring system confirms the initial estimates as to the level of use in Sections 1, 2 and 3, which were recorded as 19,914, 12,849 & 3,160 people respectively. As expected the largest number of visitors was recorded during the spring and summer months with most during the 10 days around the Easter Bank Holiday, accounting for 42% of the total for that month. Saturdays and Sunday were the busiest days of the week as shown in Figure 3.2.

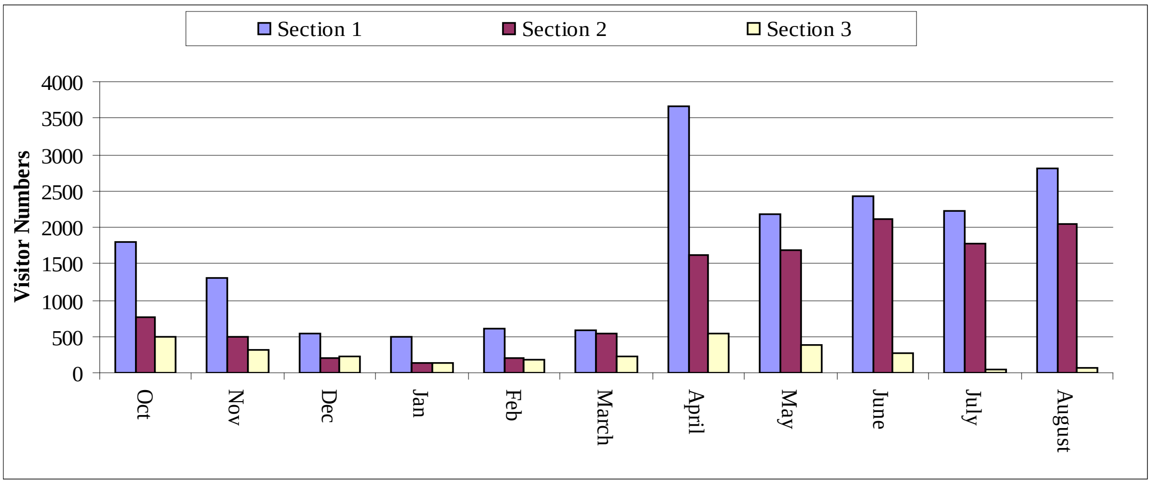


Figure 3.1 Monthly Visitor numbers from sections 1, 2 and 3 for the period from the 1st October 2006 to 30th August 2007.

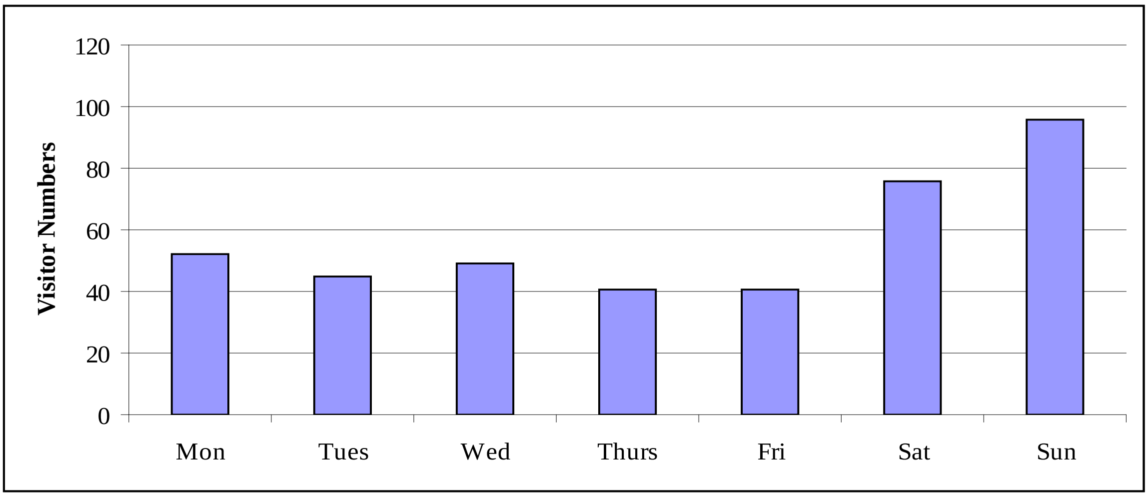


Figure 3.2 Mean number of visitors for each day of the week during the entire sampling period for section 1 of the Millennium Tail.

3.3 Vegetation and bare ground

3.3.1 Sward heights

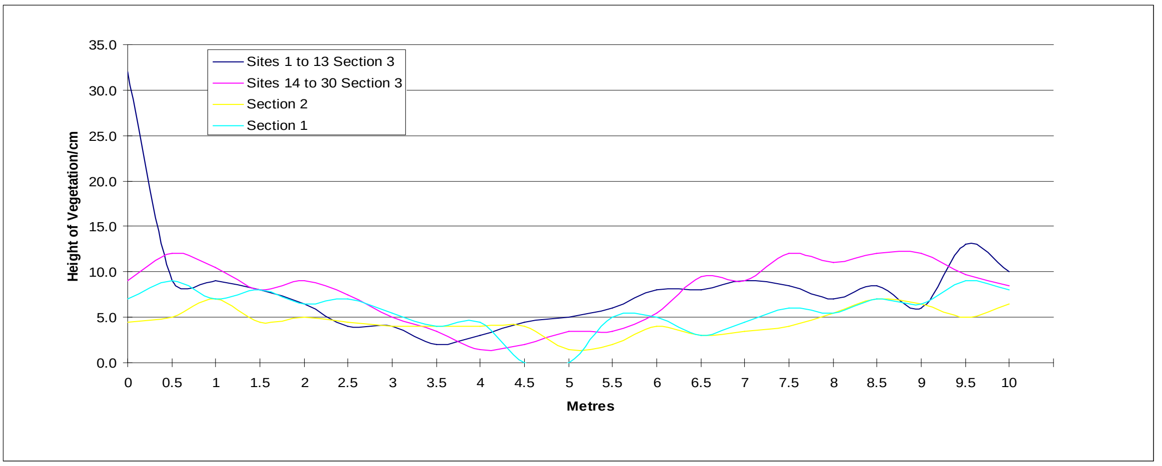
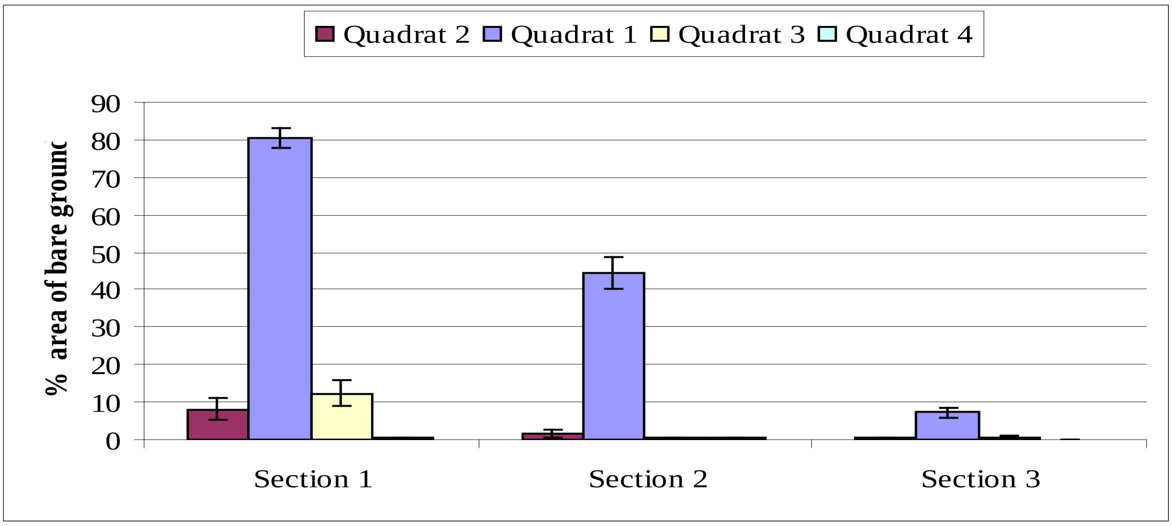


Figure 3.3 Mean sward height of sections 1, 2 & 3 (n_{total}= 600 *per* section). Measurements taken during the summer collection period.

Swards heights for section 1 range from 0 cm at the centre of the path (quadrat 1) rising sharply to 5.5 cm at the edge of the bare ground, before declining in the transition zone (an area ranging from 3 cm to 5 cm in height) then levelled out at 7 to 10 cm for 8 m, before falling again at quadrat 4 to between 3-4 cm. The profile of section 2 reflects the topography; with sward height barely exceeding 5.5 cm along the whole transect line. At the centre of the path the height of the sward decreases to 1.5 cm, the transition zone extending for 2- 3 m from the centre. The first stretch of Section 3 (from sites 1 to 13) reflects the proximity of the hedge, 2 m to the east of the middle of the path. The vegetation along the hedge side of the route measures 30 to 35 cm (this measurement was only limited by the height of the measuring rod), the transition zone of this stretch is reduced to a little over 1 m in width. Along the middle of the path vegetation reaches a similar height to that of section 2 (2 cm) with a transitional zone of 1.5 m to 2 m levelling out then remaining at around 10 to 15cm. The low stretch of Section 3 (transect 14 to 30) opens out into a hay meadow where the profile levels off in a similar manner to Section 2, with vegetation height at the centre of the path around 1.5cm. The transition zone extends a further 1 m from the centre of the path. At quadrat 2 the mean sward height reaches 6 cm to 7 cm, while at quadrat 3 vegetation height reaches only 3 cm to 4 cm, rising to 12 cm either side of the path. Data on sward height would support hypothesis 1 that sward height, as a measure of vegetation abrasion, has an inverse relationship with levels of trampling as indicated by user numbers.

3.3.2 Bare ground

a



b

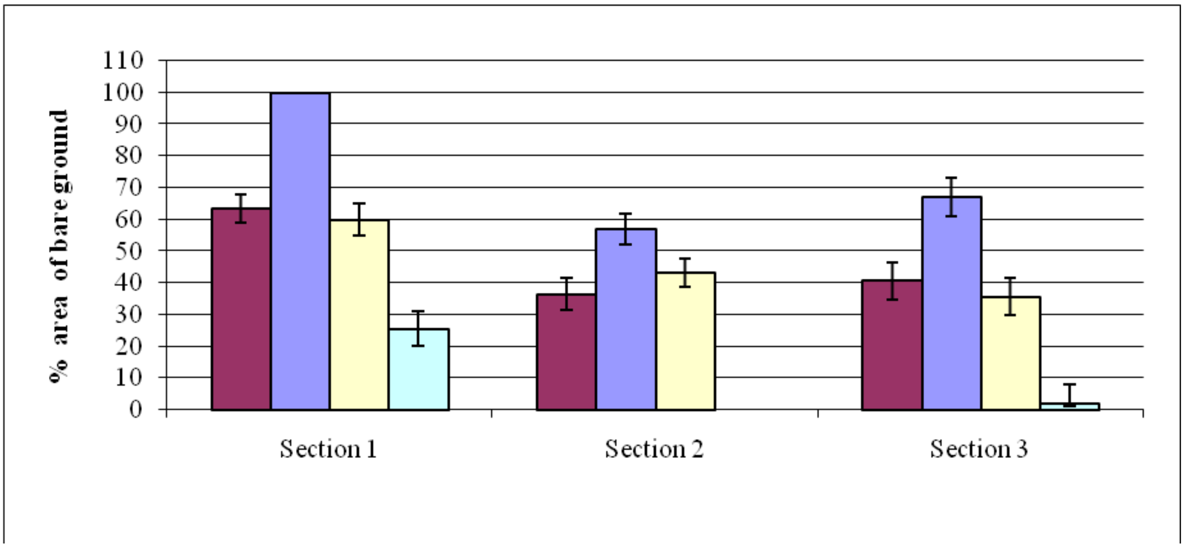


Figure 3.4 Mean area of bare ground (*n = 30*) a = summer data and b = winter data. Error bars indicate standard error.

Figure 3.4 clearly shows the greater area of bare ground in the winter over all levels of use and across all quadrats. Figure 3.4a (summer) shows a sharp decline in bare ground with decrease in level of use, while in Figure 3.4b (winter) the difference between quadrat 1 and quadrats 2 and 3 is less marked. In both summer and winter there is a greater area of bare ground in the transition zones (quadrats 2 and 3) than in the un-trampled zone (quadrat 4) and in section 1 compared to sections 2 and 3. In fact the amount of bare ground in quadrats 2 and 3 is very similar, during both summer and winter. Overall the data support hypothesis 1, as the area of bare ground generally increases as user levels increase. The differences between Figures 3.4a and 3.4b also demonstrates the strong influence of seasonality on the amount of bare ground, as although user numbers were lower in the winter the area of bare ground was greater. The relative influence of season over user level may also explain the negligible difference in bare ground between sections 2 and 3 during the winter, as user levels were limited in both sections at that time. Furthermore, data from across the paths indicates a general pattern in the distribution of bare ground, with the greatest areas of bare ground being along the centre of the path, where use is greatest, reducing further away from the centre as use becomes less.

3.3.3 *Gramineae* cover

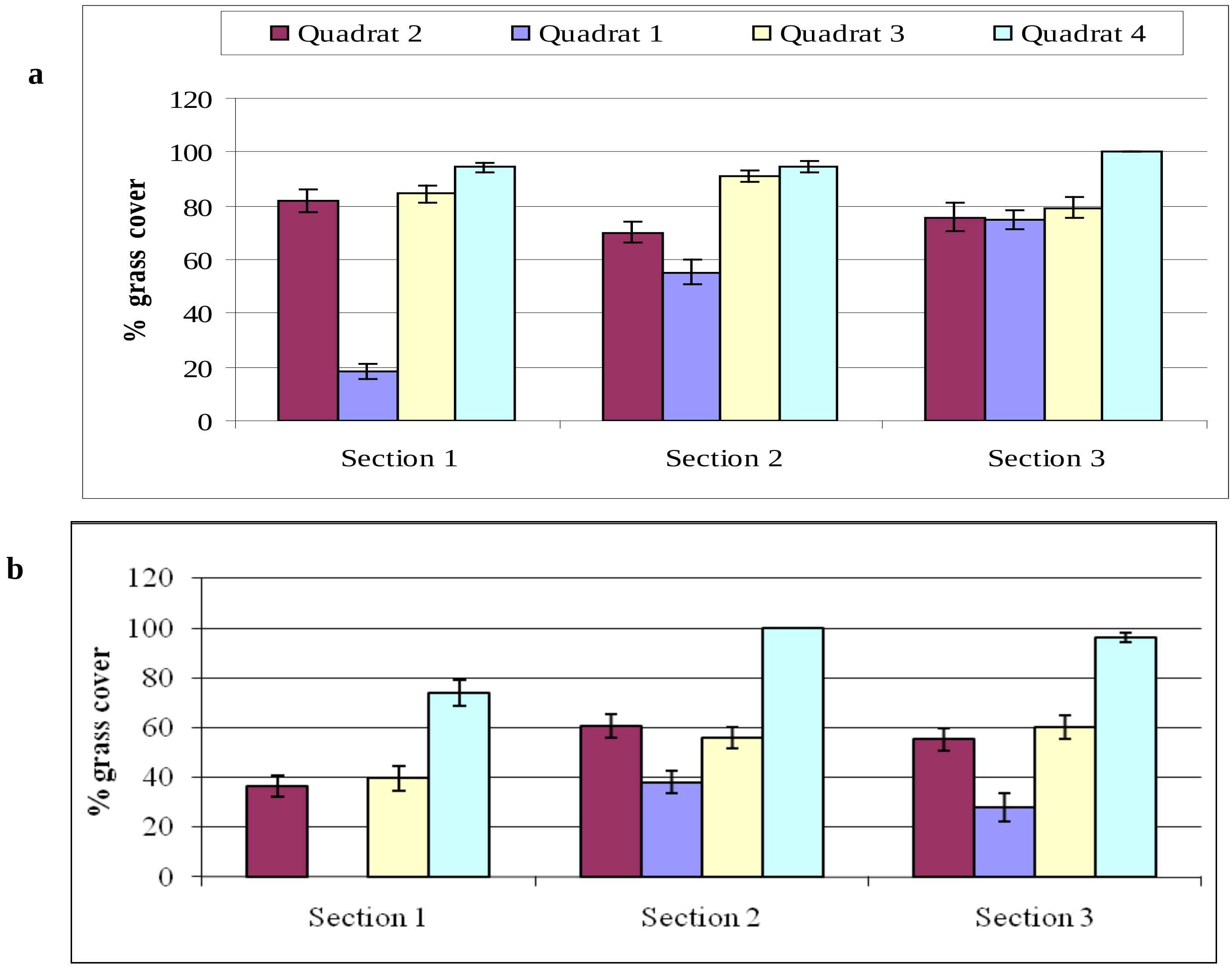
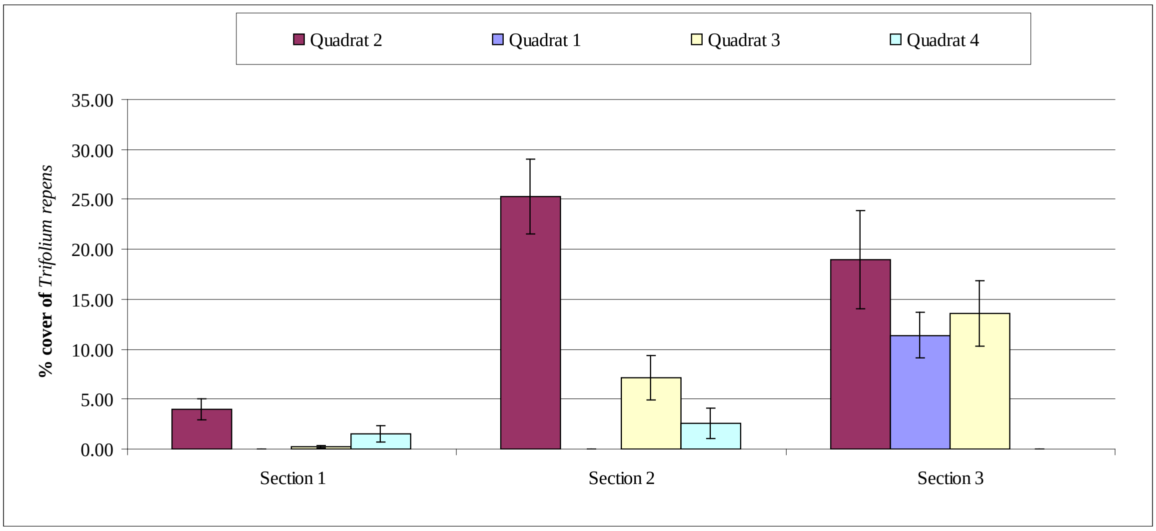


Figure 3.5 Mean cover of *Gramineae* (n= 30) a) summer, b) winter. Bars indicate standard error

Gramineae cover follows the expected pattern of an inverse relationship with user levels and corroborates hypothesis 1. This is particularly clear in quadrat 1 (centre of the path) during the summer. Although, during both summer and winter, grass cover remains similar in the transition zones (quadrats 2 and 3) across all sections, cover values remain consistently higher in all trampled areas (quadrats 1 to 3) during the summer compared to winter. During both summer and winter the un-trampled areas (quadrat 4) remain the areas with the greatest cover of grass. Interestingly, during the summer in section 3 there is almost no difference in cover between the centre of the path and the transition zones. During the winter there is a less defined relationship between user levels and vegetation cover particularly in quadrat 1, demonstrating the influence off seasonality on the date.

3.3.4 *Trifolium repens* cover

a



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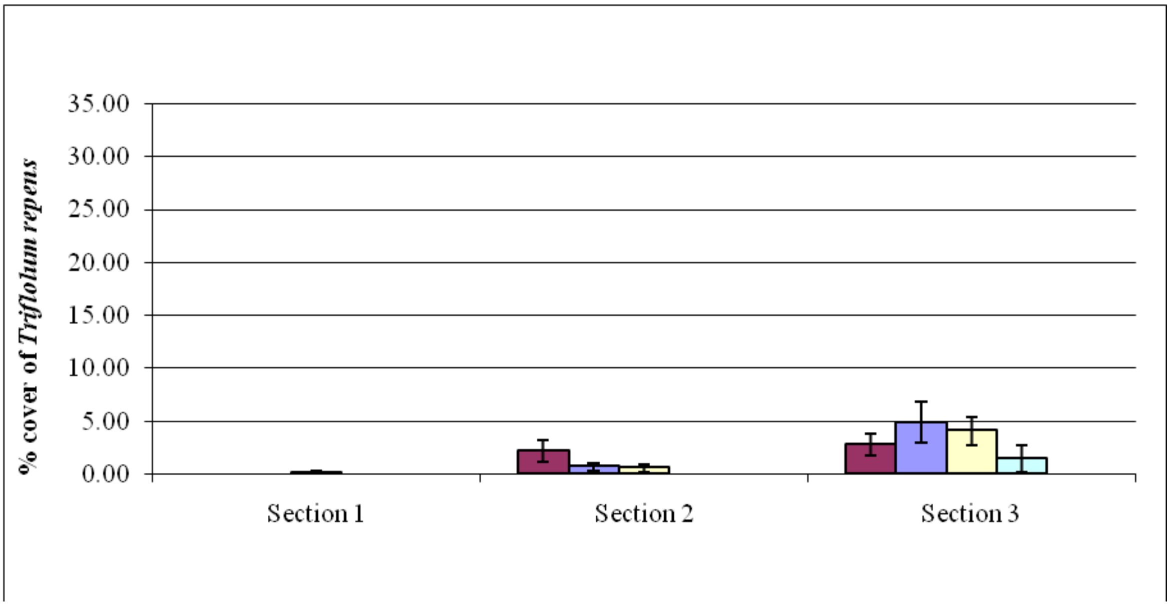
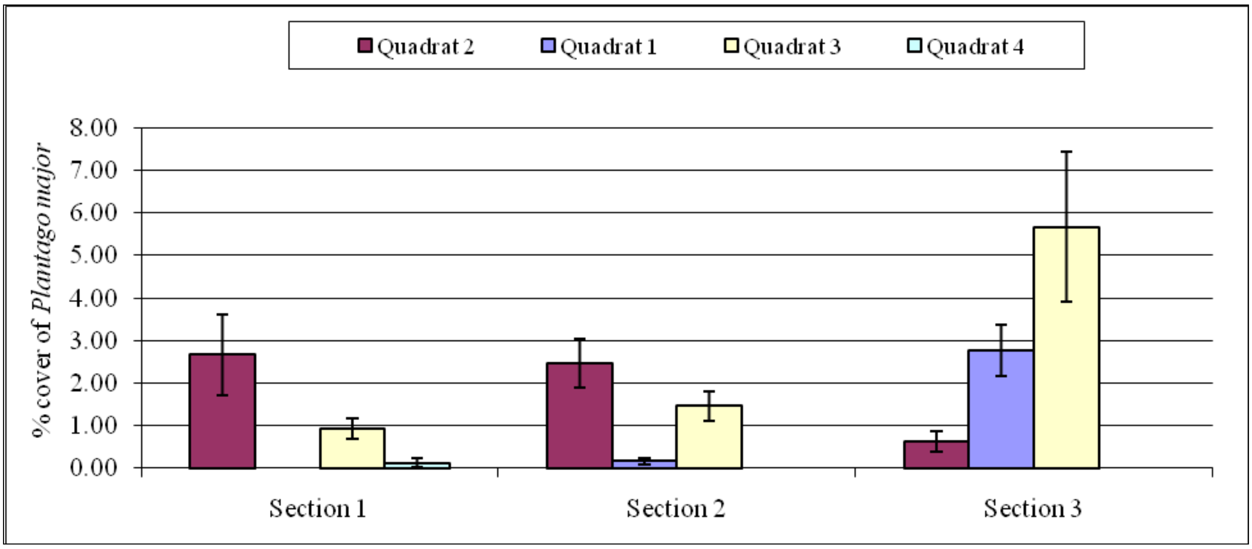


Figure 3.6 Mean cover of *Trifolium repens* (white clover) (*n*= 30) a) summer b) winter. Error bars indicate standard error.

The data from the summer and winter periods suggests that the percentage cover of *Trifolium repens* has an inverse relationship with the level of use, in the trampled zone (quadrats 1 to 3). However, away from trampling, levels of *Trifolium repens* were very low (quadrat 4). Cover was consistently higher in summer than in winter. During the winter the relationship between cover and use is less clear and confounded by the fact that levels of cover were generally very low and subject to considerable variability. This data, for summer at least, also supports the prediction of hypothesis 1 of decreasing cover with increased user levels.

3.3.5 *Plantago major* cover

a



b

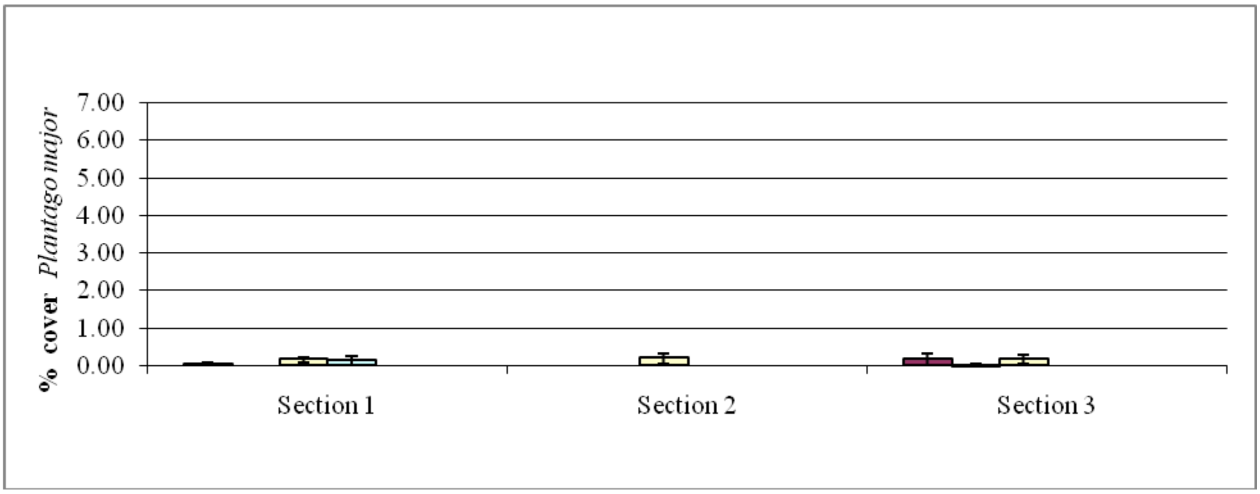
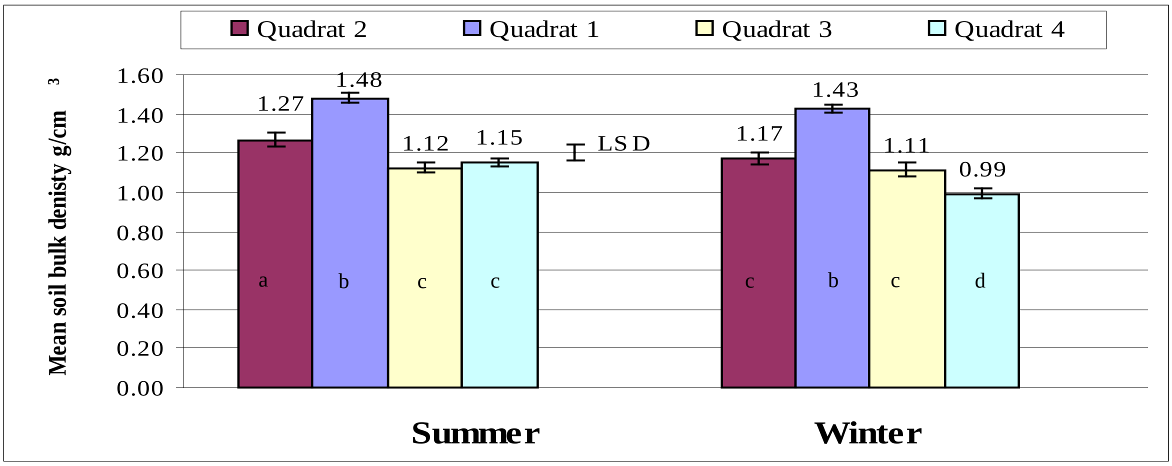


Figure 3.7 Mean cover of *Plantago major* (*n*= 30) a= summer and b = winter. Error bars indicate standard error.

During summer a similar inverse relationship to that with *Trifolium repens* exists between user numbers and *Plantago major* cover and was sufficient to severely limit *Plantago major* presence in quadrat 1, until section 3. Across all sections during the summer, the highest cover of *Plantago major* was found in the transition zone (quadrats 2 and 3) although this relationship was far less clear in winter, when very limited cover existed. As with *Gramineae* and *Trifolium repens*, seasonality clearly plays an important part in the cover of *Plantago major*. Interestingly, as with *Trifolium repens, Plantago major* cover was very low or entirely absent in un-trampled areas, suggesting an association with physical disturbance. The preference of *Plantago major* for areas where some physical disturbance has occurred e.g. the transition zones and its greater abundance in quadrat 1 over quadrat 2 in section 3 of the path during summer, also suggest a tolerance effect at low user levels, supporting the prediction of hypothesis 2.

3.4 Soil bulk density

a



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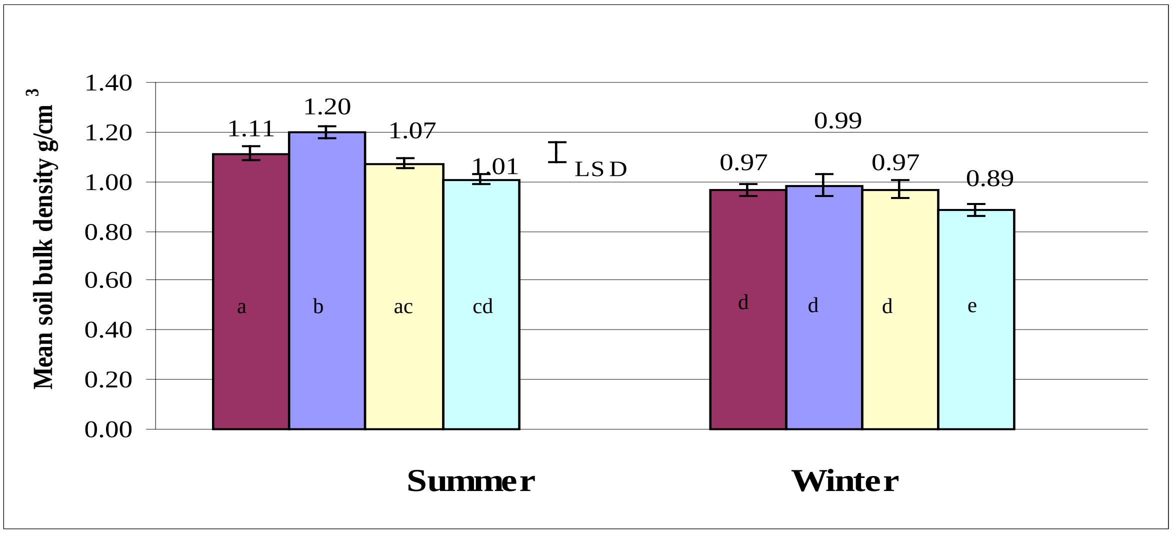

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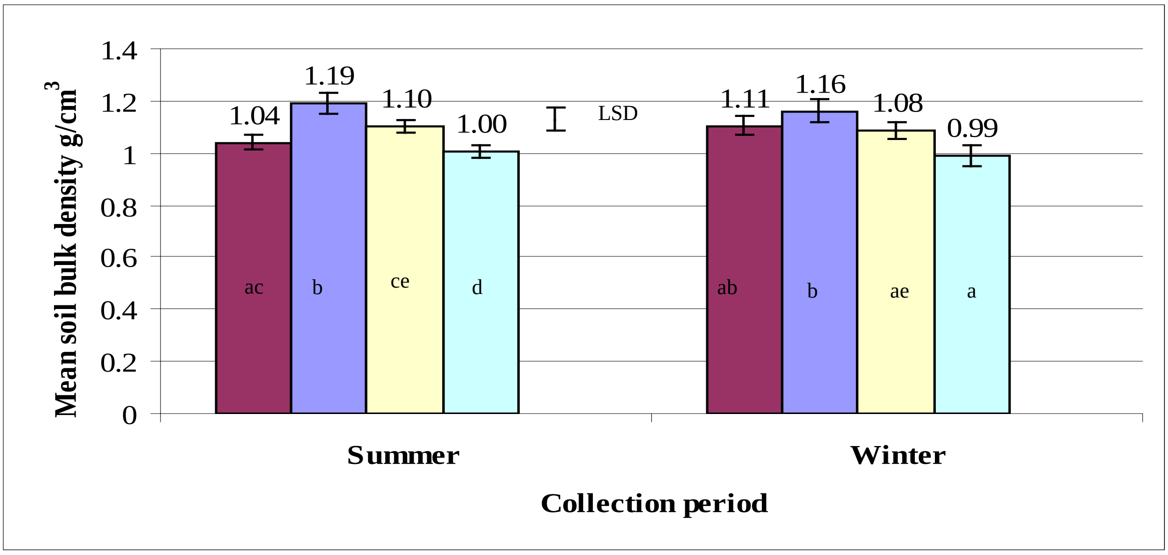


Figure 3.8 Mean soil bulk density g/cm^3 values (*n=30*), a) section 1, b) section 2, c) section 3, during both collection periods. Error bars indicate standard error. Bars with the same letter do not vary significantly from one another (P < 0.05) within each section.

3.4.1 Differences in soil bulk density across the path and between seasons

3.4.1.1 Section 1

ANOVA identified a significant overall difference between summer and winter ($P < 0.001$) and that the position across the path also had a significant influence on bulk density ($P < 0.001$). Although ANOVA showed a significant overall difference between seasons, LSD identified that neither summer nor winter had a significant effect on the bulk density along the centre of the path, but there was a significant difference between quadrats 2 and 4 in both seasons. It was also found that season had no significant effect on the bulk density values in quadrat 3 of the transitional zone. From the summer data, LSD showed that location across the path had a significant effect on the bulk density of all quadrats, except between quadrats 3 and 4. Winter data showed that the only of quadrats that did not differ significantly in bulk density ($P < 0.05$) were those in the transition zone (quadrats 2 and 3).

3.4.1.2 Section 2

ANOVA showed that season had a significant influence on bulk density ($P < 0.001$) as did position across the path ($P < 0.001$). LSD identified that during the summer there was a significant difference between the centre of the path (quadrat 1) and all the other zones. Although, there was a difference between quadrats 2 and 3 in the transition zone, LSD showed this not to be significant. Between the transition zone and the un-trampled zone the only significant difference in bulk density was found between quadrat 4 and quadrat 2 ($P < 0.05$). During the winter the only significant difference ($P < 0.05$) was a lower bulk density in quadrat 4 compared to the other 3 quadrats.

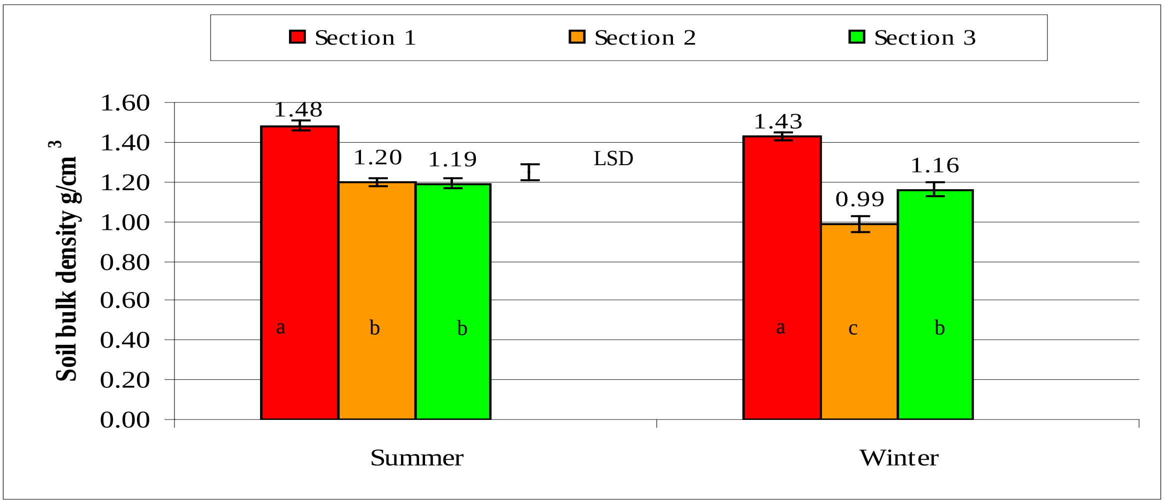
3.4.1.3 Section 3

ANOVA ($P < 0.05$) showed a significant difference in bulk density with position along the transect ($P < 0.001$), but not between summer and winter. During the summer LSD ($P < 0.05$) identified the differences in bulk density to be significant between quadrat 1 and quadrats 2 and 4, and also between quadrats 3 and 4, but no significant difference between quadrats 2 and 3. The winter data showed the same pattern of decline in bulk density away from the centre of the path and ANOVA showed this to be significant ($P < 0.001$) in all cases. Again, no significant difference was identified in the transition zone between quadrats 2 and 3 ($P < 0.05$), or between these quadrats and quadrat 4.

Overall across all sections quadrat 1 generally had significantly higher bulk density than the other quadrats providing support for the link between user numbers and bulk density predicted in hypothesis 3.

3.4.2 Difference in soil bulk density between sections

a



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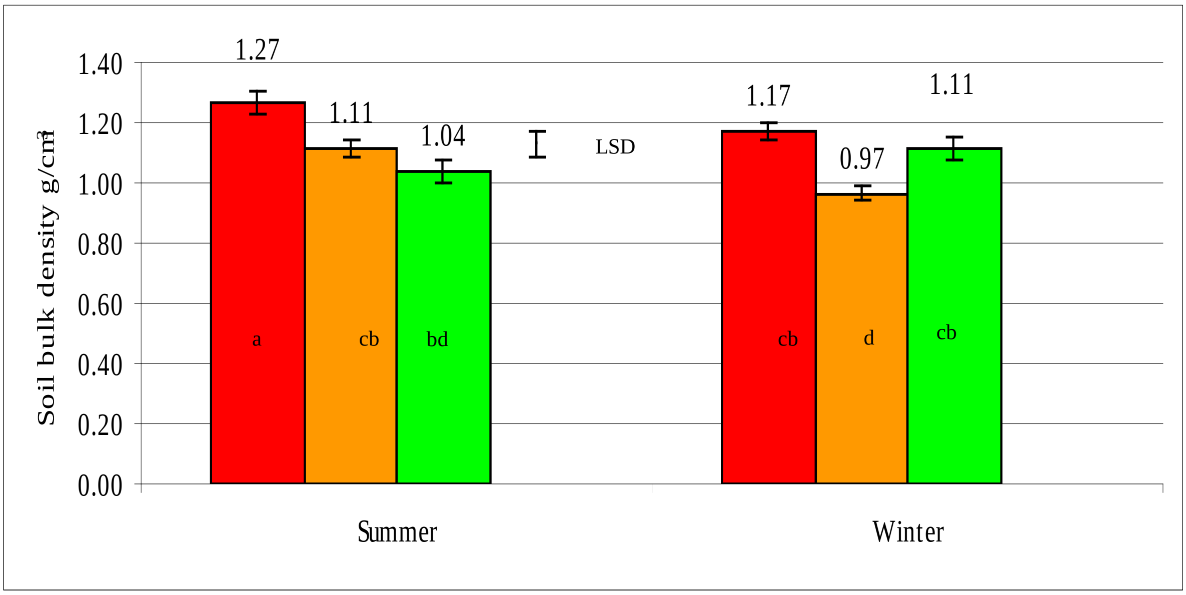

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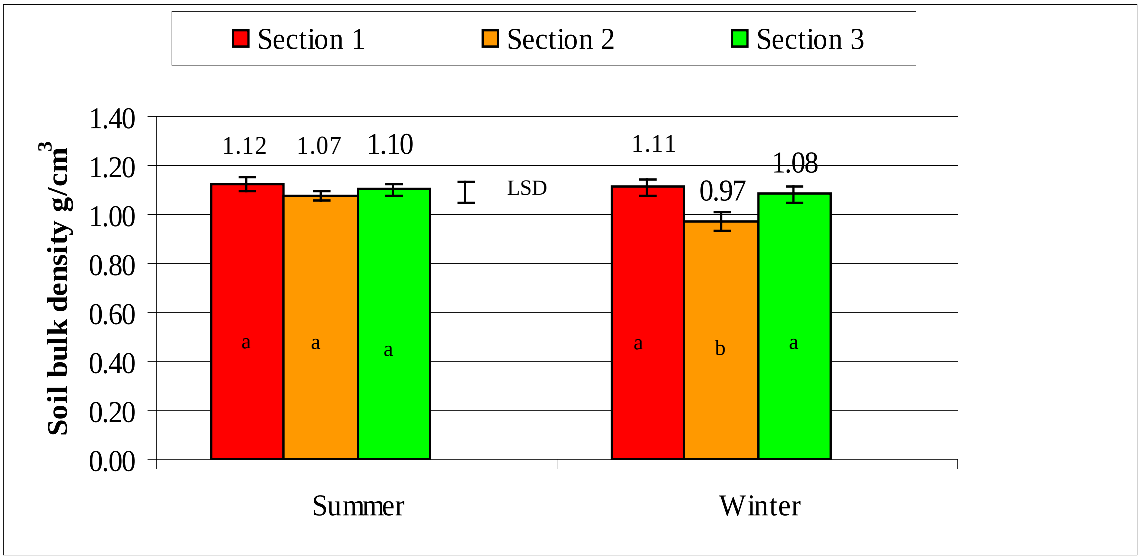

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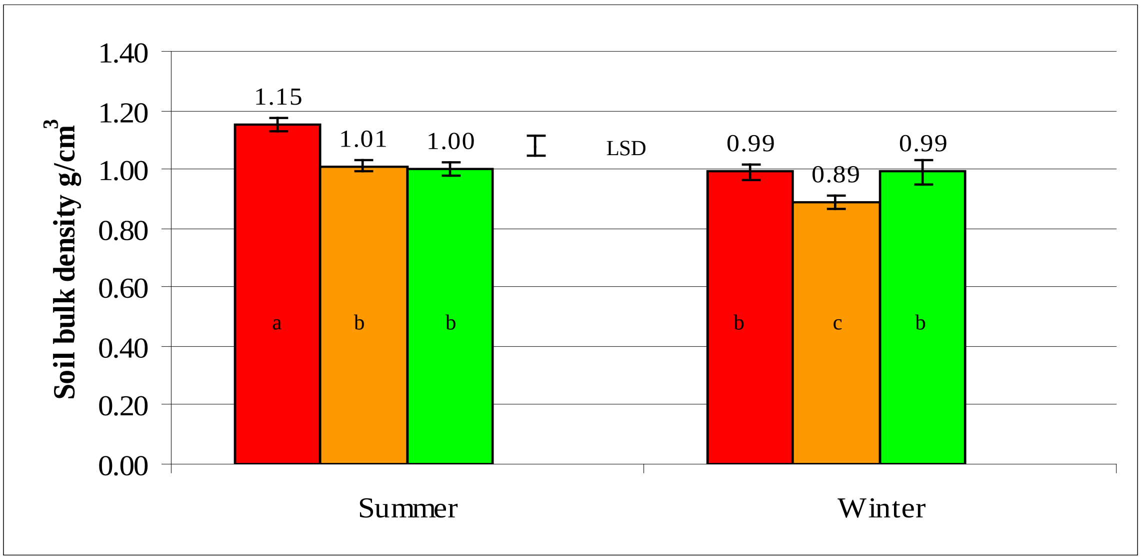

Figure 3.9 Mean soil bulk density g cm^{-3} values (*n=30)* between sections along the path, a) Quadrat 1, b) Quadrat 2, c) Quadrat 3 and d) Quadrat 4, during both collection periods. Error bars indicate standard error. Bars with the same letter do not vary significantly from one another ($P > 0.05$).

3.4.2.1 Along the centre of the path (quadrat 1)

Summer bulk density values along the centre of the path show a decline, with user levels, although these were only shown to be significant (P= <0.05) between sections 1 and 2 and between sections 1 and 3. Winter bulk density was significantly ($P = 0.05$) higher in section 1 compared to section 2, or section 3.

3.4.2.2 Along the transition zones (quadrat 2)

For quadrat 2 although ANOVA (P = 0.05) indicated that user levels (sections) had a significant influence on bulk density during the summer, although a significant difference was only found between section 1 and sections 2 and 3. During the winter ANOVA suggested that user pressure had even less influence on bulk density, with significantly lower bulk density in section 2 compared to sections 1 and 3. Interestingly, LSD identified that bulk density in sections 1 and 2 declined significantly between summer and winter but showed no significant change in section 3

3.4.2.3 Along the transition zones (quadrat 3)

In quadrat 3, ANOVA identified a significant overall difference between user levels but not between seasons. However, differences in user levels (between sections) were only significant during the winter with sections 1 and 3 both having significantly higher bulk density than section 2.

3.4.2.4 Along the un-trampled zone (quadrat 4)

In the un-trampled zone (quadrat 4) ANOVA (P=0.05) showed that both seasons and user levels had a significant influence on bulk density. During, summer this was limited to bulk density being significantly higher in section 1 than in sections 2 and 3, whereas during the winter both section 1 and section 3 had significantly higher bulk density than section 2. Overall across all quadrats, bulk density in section 1 was significantly higher than that in sections 2 and 3 for both summer and winter, supporting the assertion of hypothesis 3 of increasing soil bulk density with increasing user levels. However, the relationship was less clear between sections 2 and 3 for all quadrats, with no significant difference in soil bulk density between these sections in summer and significantly greater bulk density in section 3 compared to section 2 during the winter.

3.5 Environmental summary

In summary, the footpath monitoring system confirmed the initial conjecture of a decrease in user numbers from sections 1 – 3.

Vegetation height both along and across the path showed an inverse relationship with user numbers supporting hypothesis 1. Although Figures 3.4a and 3.4b demonstrate the strong influence of seasonality on the amount of bare ground, within each season data from long the path, generally showed a significant positive correlation with user numbers (Appendix II). Across the path in Figures 3.4a and 3.4b a similar pattern can be identified, with the proportion of bare ground reducing away from the centre of the path again supporting hypothesis 1.

As with bare ground and *Gramineae* cover seasonality had a strong influence on the proportion cover of *Trifolium repens* and *Plantago major*, with only summer producing any meaningful data to compare. Across the path the greatest cover of both *Trifolium repens* and *Plantago major* was in the transition zones, with little or nothing recorded in quadrat 4 for either species. It is not until section 3 that *Trifolium repens* is recorded along the centre of the path, while *Plantago major* is recorded along the centre of the path in section 2. Both species showing a significant ($P <0.001$) negative correlation with user numbers (Appendix II). The lack of either species along the centre of the path in section 1 would suggest that whilst growth of each is encouraged by a moderate level of disturbance, they disappear when use becomes too great. This change in the proportion of cover of each species would support hypotheses 1 and 2 in that one of the effects of trampling is a change in species composition.

The bulk density results for sections 1 and 2 indicate that both time of year and the position along the transect influenced soil bulk density, while in section 3 only the position along transect the influenced bulk density. Along the path both user levels and time of year significantly affected bulk density in the centre of the path, in the transition zone only user levels had a significant impact on bulk density, while along the un-trampled zone both user levels and time of year had a significant influence on bulk density.

These soil bulk density results would support hypotheses 3, in that an increase in user level does increase soil bulk density, however, they also identify the influence of seasons.

Hypotheses 4 suggested a possible relationship between increased soil compaction and increased *Plantago major* abundance. However, in general the opposite effect was apparent with less *Plantago major* with more trampling in sections 1 and 2 and no clear relationship in section 3. Furthermore, with the exception of quadrat 2 during the summer, no significant correlations were identified between *Plantago major* and soil bulk density during either summer or winter (Appendix II).

CHAPTER 4: DISCUSSION

This aim of this study was to investigate if *Plantago major* cover can be used as an indicator of user levels and the early stages of soil erosion, before the stage is reached where the loss of vegetation cover results in soil loss. It also amid to assess its potential as an aid to the management of soil erosion, resulting from the impact of human trampling on the Public Footpaths of Warwickshire from both an economic and aesthetic perspective.

There is limited up to date information on the cost of erosion generated from human trampling on minor public rights of way. Evans (1996), using data from local authorities, estimated that footpath erosion cost UK agriculture £1.19 million in lost soil, the cost of which is only set to rise as rainfall intensity is predicted to increase as a result of climate change. However, the cost of erosion is not just borne by the agricultural industry; the cost of remedial work often falls on the responsible authority, whose ability to allocate funds for erosion control is limited by available budget rather than demand (Lake District National Parks Authority 2007). However, along with an increase in the number of users is an increase in the standard of surfacing expected, this has resulted in greater demand from user groups e.g. Ramblers Association and horse riding groups, for remedial action (Fry personal communication 2007). This coupled with higher labour and material costs, add to the pressure on recreational professionals to find alternative methods of managing these impacts (Kozlowski 1999).

Early detection of these problems can substantially reduce the amount of work required and therefore the cost of any remedial work (Lake District National Parks Authority 2007). However, many of the methods used for detecting the early stages of erosion are either expensive, requiring professional soil analysis, or rely on visual signs such as an increase in bare ground which, it has been argued, is too late as the breakdown in soil structure has already occurred. Therefore, with increasing pressure on their budgets land managers are looking for a method which can indicate the current state of the soil and its susceptibility to erosion.

In this study, bare ground was considerable along the centre of the path (quadrat 1) in section 1. However, given the number of visitors, it must be questioned why sections 2 and 3 do not also show larger areas of bare ground. Liddle (1997) suggests that it is important to consider not only the number of visitors (intensity), but also their distribution over time (frequency). In this study, although visitor numbers were high, they were spread over 350 days; indeed in section 1, only 5 counts exceed 200 visitors in one day. Along section 2, on only 6 days did visitor numbers exceed 150 and in section 3, there were only 3 days when numbers exceeded 50. These figures indicate that on no days did user numbers exceed the levels indicated by previous studies needed to reduce vegetation cover by 50% - the critical limit identified by Liddle (1997) above which wind and rain can begin the detachment and transportation of soil particles (arguably the first and second stages of erosion). This frequency of visits over a 1.35 km length of path coupled with the ability of *Lolium perenne*, which dominate the sward, to re-colonise quickly during the spring and summer growing seasons (Bond, Davies and Turner 2007a), may have contributed to the low proportion of bare ground, particularly along sections 2 and 3.

Along the path, with the exception of quadrat 4 (summer) bare ground showed a significant positive correlation with user numbers in all quadrats (Tables 3.4 and 3.5), the strongest being during the summer in quadrat 1 (r = 0.870), with little difference in the area of bare ground between quadrat 2 and quadrat 3 of the transition zones. Although, the results clearly show that position, both along and across the path are important factors in the amount of bare ground, the difference in season is also a key factor. Indeed, how vegetation and soil respond to user pressure is very dependent on season. This is shown in Figure 3.4, where there is a marked difference in the area of bare ground between summer and winter, especially along the transition zones, with the largest area being during the winter, even though visitor numbers were lower than during the summer.

This difference in bare ground can be attributed to a number of factors, particularly the significantly (P<0.001) higher soil water content during the winter compared to summer. This difference might not be expected given that during the study period more rain actually fell during the summer (May, June, July and August) than during the winter (October, November, December and January) with totals of 440.25 mm and 423.00 mm respectively. However, as suggested by Cole (2004), this discrepancy between rainfall and soil water content can be attributed to, lower temperature, reduced evaporation, less plant growth resulting in less transpiration and the reduction in infiltration rates resulting from compaction (increasing runoff). Despite the compounding effect of season, there is no doubt that overall the data collected in this study supports the model in Figure 1.1, that increases in trampling as indicated by user levels reduces the amount of vegetation cover as evidenced by the increase in the area of bare ground and the reduction in vegetation height. This supports the assertion of hypothesis 2.

Kuss (1986), suggest that as moisture content increases, soil cohesion decreases, changing the soil consistency from firm to plastic (mud) and reducing its ability to resist any force. Consequently, as observed during site surveys of section 2, as one area became muddy and un-passable users tended to spread out widening the path (see Figure 4.1). This, coupled with the reduced growth rate of vegetation during winter, resulted in larger areas of bare ground during the winter and is most obvious in the changes in the transition zones between summer and winter (Figure 3.4).

Figure 4.1 The extent of bare ground in section 2 resulting from visitor's walking patterns. Photograph taken during January 2007

ANOVA indicated that both season and position across the path had a significant influence on compaction/bulk density. However, LSD indentified that, there was no significant difference between quadrats 2 and 3 of the transition zones (Figure 3.8), suggesting that both sides of the path received similar levels of use. Indeed, with the exception of section 2 (winter), no significant difference was identified in quadrat 3 along the whole length of the path (Figure 3.10c). As seen in Figure 3.8b, bulk density values for section 2 (winter) represent something of a curiosity, being consistently and significantly lower than both sections 1 and 3 during the winter. Also, with the exception of quadrat 4, which is 10 metres from the centre of the path, there is no significant difference between the other quadrats in section 2, during the winter. This would seem to underline the fact that walkers are not confined to the centre of the path in section 2, especially during winter. A further explanation for the low bulk density values in Section 2 may be the slight difference in the winter data collection dates between the sections. Due to time constraints, data from sections 1 and 3 were collected during the 1st week of November 2006, whilst that for section 2 was collected during the 2nd week of January 2007, which was the lowest month for visitors (Figure 3.2). Although ANOVA indicated an overall significant difference in bulk density between seasons in sections 1 and 2 but not in section 3, LSD identified that there was no significant difference in compaction between summer and winter along the centre of the path in section 1 or section 3 (Figure 3.8).

Interestingly, during the summer, with the exception of quadrat 3 there is a significant decrease in bulk density along the path in all other quadrats between sections 1 and 2 and between sections 1 and 3, but not between sections 2 and 3. This decrease is most marked along the centre of the path (Figure 3.10). Previous research, and the marked difference in user numbers between sections, would have suggested that there would be a steady linear decline in bulk density in line with user numbers; however this is not the case.

The changing topography along the path may have an influenced the spatial distribution of walkers. The slope along most of section 1 forces walkers to stay along the centre of the path, so increasing compaction. Along section 2 the ground levels out and is more open, allowing walkers to spread out (see Figure 4.1), particularly when walking in groups. It is easier to communicate whilst walking side by side, which may explain the extended width of the transition zone along this section of approximately 2- 3 metres, thereby lessening the impact of the 12,849 recorded visitors in this section on the soil. This suggests that the mean bulk density value of 1.20 g cm^{-3} is not a true reflection of the impact of 12,849 walkers during the summer period. Also contributing to this lack of any linear decline in bulk density, may be the proximity of the hedge to the path along the first stretch of section 3 from site 1 to site 14, forcing walkers to concentrate along the centre of the path as opposed to spreading out as in section 2. Indeed, 1.19 to 1.20 g cm^{-3} may well be a truer reflection of the bulk density associated with circa 3,000 visitors rather than over 12,000 visitors.

These bulk density values and vegetation cover would appear to be supported by the findings of Chappell *et al.* (1971); Quinn, Morgan, and Smith (1980) and Roovers Baeten and Hermy 2004), who suggest that the breakdown in soil structure (arguably the start of the erosion process) occurs early in path creation, while vegetation cover is still dense. In section 3, for example, a significant increase in bulk density (P<0.001) between the un-trampled zone and the centre of the path was accompanied by only a 7.20% increase in bare ground. This is also the case in sections 1 and 2, where significant increases in bulk density between the un-trampled zones and the transition zones are accompanied by only small losses in vegetation cover. Results from across the path in general show a significant difference between the centre of the path and the other zones and along the path between the other sections and section 1. However, there is, with the exception of section 2 (winter) in general no significant difference within the transition zones or between summer and winter values from that zone, which would suggest that the level of use is similar either side of the centre of the path. The significant difference between quadrat 4 and the centre of the path suggest that user levels have an influence on bulk density values. This provides support for hypothesis 3 in that as user levels increase soil bulk density also increases, although only up to a point.

Interestingly, examination of vegetation cover between winter and summer indicates that cover actually increases in all areas, highlighting the conflicting processes represented by the destructive action of trampling and recovering growth (resilience) of the sward. Indeed, this difference in vegetation cover between summer and winter, is far more marked for *Trifolium repens* and *Plantago major* than *Gramineae*, and also in quadrat 1 (centre of the path) than the other zones. This is likely a reflection of the different resilience of each species/taxa. Unlike *Trifolium repens* and many *Gramineae* species, which have the ability to undergo substantial vegetative re-growth (through stolons or adventitious root systems), *Plantago* species mostly have only limited vegetative reproductive capabilities. *Plantago major*, for example, produces daughter rosettes from lateral buds, while Ribwort Plantain (*Plantago lanceolata)* can produce short rhizomes, both preferring to reproduce by seeds, which germinate mainly between April and August (Bond, Davies and Turner 2007c). More importantly, in the context of this study, is that *Plantago* overwinter either underground or as small rosettes, losing their above ground tissue (iteroparous) and re-emerging in spring (Lotz 1990). This dormancy during winter and re-emergence in spring is reflected in the marked difference in cover between summer and winter (Figure 3.7). In contrast, the quick recovery and stoloniferous re-growth of *Trifolium repens* enables it to rapidly colonise areas of bare ground, dominating the sward compared with *Plantago*. As seen in Figure 3.5, there is a less marked difference in the grass cover between summer and winter. This may largely result from the grass sward being dominated by *Lolium perenne*, which in a temperate climate such as the UK is very persistent (Bond, Davies and Turner, 2007a), enabling it to re-colonize areas quickly. Indeed, *Lolium perenne* is planted for this very reason, as it provides rapid cover in the control of soil erosion.

Bond, Davies and Turner (2007b), suggest that the absence or negligible cover of *Trifolium repens* in the untrampled zone (quadrat 4), reflects its tendency to be suppressed by taller grasses which, according to Engelaar and Blom (1995), is also the case with *Plantago major.* Further inspection of the data in Figures 3.6 and 3.7 from along the centre of the path, shows that during the summer both *Trifolium repens* and *Plantago major* were almost absent in sections 1 and 2 and only present in significant quantities in section 3. This helps to explain the significant ($P<0.001$) overall negative correlations found between cover and both user numbers and bare ground for these species (Table 3.4). The negative correlation between bare ground and *Plantago major* cover is somewhat surprising as, according to Hirst *et al.* (2003), *Plantago* major require areas of bare ground for seed germination during the spring. Unfortunately, due to exceptionally high rain fall during the key germination period of May to July (Table 3.1) no survey was carried out during this time.

The work of Bond, Davies and Turner (2007b, 2007c) may help to explain this apparent anomaly. They suggest that the optimum emergence depth for *Plantago* is between 0 and 5 mm of soil, with a maximum of 10 mm. This depth of soil can, in areas of bare ground with high levels of use, as was the case in this study, easily be removed by the action of walkers. In the case of *Trifolium repens,* where the main reproductive method is the stolon, the sheering action of walkers, as described by Quinn, Morgan, and Smith (1980), is enough to remove the stolon. Also, it is worth remembering that in the case of both *Trifolium repens* and *Plantago major*, the time optimum for growth and germination is April, May and June, which according to Figure 3.1 was the time of peak traffic along the path. This may well explain the absence of both *Plantago major* and *Trifolium repens* from areas of high use e.g. along the centre of the path in sections 1 and 2, with the trampling action of walkers removing the young seedlings or stolons before they develop. It is not until section 3 where use pressure is considerably reduced, that *Trifolium repens* and *Plantago major* begin to thrive.

There is little doubt that trampling influences the coverage of *Plantago major*. However, as it is important to discriminate between the effect of trampling as a whole and that of compaction, as it is often difficult to separate the influence of these individual factors. Hypothesis 4 predicts that increases in soil compaction, as measured by soil bulk density will increase cover of *Plantago major*. However, results from this study would suggest that this is not the case. The presence of *Plantago major* recorded in areas with bulk density values ranging from 1.04 g m^{-3} to 1.27 g m^{-3} would suggest that the level of compaction, in this study, does not influence the occurrence of the species. Furthermore, in general there is no significant correlation between *Plantago major* and soil bulk density (Table 3.4). This lack of any significant correlation between the occurrence of *Plantago major* and bulk density along the path (Table 3.4), may be as explained by the work of Dijkstra and Lambers (1989) and Engelaar, Jacobs and Blom (1995) who suggest that the resistant root system of *Plantago* can withstand the levels of compaction encountered anywhere along the path in this study. However, there is a significant correlation with user numbers (r = -0.519) and bare ground (r = -0.439) along the centre of the path suggesting a relationship with trampling. It is quite possible that trampling is having an effect on the vegetation without this having to be mediated through soil compaction. As emphasised by Cole (2004), compaction is only one consequence of trampling. The abrasion of surface vegetation is a more direct effect, which is reflected in the change in sward height both long and across the path as described in Section 3.3.1. Results from across the path (Figure 3.7a) show that *Plantago major* favour the transition zones (quadrats 2 and 3), where the level of use is less, indicating a threshold in the sward height of 1.5 to 6 cm, in which *Plantago* is able to survive. Warwick (1980) suggests that a certain level of vegetation cover offers *Plantago* an element of cushioning and protection from the direct effects of trampling (abrasion of vegetation), while in swards > 6 cm *Plantago major* begin to decline (Engelaar and Blom, 1995) as they lose out to more competitive species for light. The presence of *Plantago major* and *Trifloium repens* in areas where some trampling (transition zones) has occurred, as opposed to their absence in areas of no trampling (quadrat 4) would indicate a change in species composition, supporting hypothesis 2 in that the changes brought about by trampling do not manifest themselves equally across all species and that *Plantago major* has an upper and lower tolerance threshold for trampling. This same pattern of preference for the transitional zone was identified by Klecka (1937) in his studies in Czechoslovakia, (as reported in Liddle 1997) and by Chappell *et al.* (1971) in their study of the effect of trampling on the chalk downlands of Hampshire UK. They observed that *Plantago* spp (in this case *Plantago lanceolata*) was more frequent in the intermediate zones, with short swards up to 5 cm but with little or no bare ground (the transition zones in this study), but declined in the heavily trampled zones (Table 4.1) i.e. *Plantago* actually declines with more use (r = -0.519).

Table 4.1 The occurrence of *Plantago* spp in relation to dry soil bulk density g cm^{-3}. The figures for bulk density and *Plantago major* cover for this study are means of all summer sections combined.

	Chappel *et al* (1971)		This Study	
	Frequency	Bulk density g/cm^3	Cover %	Bulk density g/cm^3
Un-trampled	56	0.681	0.04	1.05
Lightly trampled	142	0.827	2.31	1.12
Heavily trampled	41	1.018	0.98	1.29

Given this, it remains important to assess if change in *Plantago major* cover can provide an indication of the likelihood of erosion. Given that the degree of soil compaction is indicated by its bulk density and that the results of this study show that there is almost no correlation between the cover of *Plantago major* and soil bulk density, it might be suggested that *Plantago major* cannot be used as an indicator. However, as discussed above, the vulnerability of the ground to erosion is not only influenced by soil structure but also by vegetation cover. While vegetation cover is sufficient to protect the already collapsing soil, little erosion occurs. However, where the loss of vegetation cover reaches the critical limits identified by Elwell and Stocking (1976) and Liddle (1997) of 30% and 50% respectively, the agents of erosion (wind, rain and human trampling) cause detachment and transportation of soil particles (arguably the first and second stages of erosion) to occur. Furthermore, Cole (2003) suggests that the action of walkers directly loosens soil particles, and this provides the conditions in which agents of erosion can operate more effectively.

It would seem, therefore, that although the increased coverage of *Plantago* is not directly linked to an increase in soil bulk density as a proxy for soil compaction, it is an indicator of increased trampling, and thus indirectly an indicator of a breakdown in the soil structure to a state where removal of vegetation cover would result in the detachment and transportation of soil particles, the visible signs of erosion.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

It is generally excepted that the magnitude of erosion impact on footpaths is a function of frequency of use, the type and behaviour of use, season of use, environmental conditions, and the spatial distribution of use. Carignan and Villard (2001) suggest that certain species with a strong association with a particular habitat characteristic can be useful indicators, if only a narrow range of ecological conditions are being investigated. This study has demonstrated the limitations of using a vegetation species as an indicator of a single environmental condition, in this case soil compaction as a reflection of the breakdown in soil structure.

As the presence or absence of a particular species, in this case *Plantago major*, is seldom, if ever, a direct consequence of a single environmental condition, it is more the influence of a combination of environmental conditions. The target ecological condition of this research was soil compaction/breakdown in soil structure (Kozlowski 1999). *Plantago* was chosen as possible indicator species of compaction following personal observation and the research of others on *Plantago's* adaption to compaction. However, results from this study clearly identify a seasonal limitation in using *Plantago* and indeed many herbaceous species as indicators of environmental conditions, as they are effective only during the growing season, with little or no cover in winter. Results indicate that *Plantago majors's* adaptations and its ability to withstand high levels of compaction are the very reason why it cannot be use as a direct indicator as in this study there was no observed level of compaction beyond which *Plantago major* could not survive, hence no significant correlation between *Plantago major* and compaction. However, the distribution of *Plantago major* across the study area would suggest that there is a relationship between trampling and *Plantago major,* although this is not linear. There is a threshold to the level of trampling above which *Plantago major* cannot survive, however the high level of this threshold is not because of compaction, more the abrasion of the above ground tissue. As discussed the direct influences of trampling are, abrasion of above ground tissue, soil compaction and the removal of the organic layer. Results clearly support the model in Figure 1.1, and hypothesis 2 that increased user levels reduce the amount of vegetation present, evidenced by a reduction in vegetation height and an increase in bare ground. It is also important to understand, when drawing any conclusions, that these signs/indicators of erosion are not mutually exclusive. The results also support hypothesis 2 in that changes in the level of trampling can change species composition. This is supported by the finding of Ikeda and Okutomi (1990) and Liddle (1997) that the increase in cover of *Plantago major* is transient, depending on seasonal variation, the plant's reproductive strategy (resilience), the plant's adaptation to mechanical damage caused by trampling (resistance) and the level of use. The abundance of *Plantago* and *Trifolium repens* in the transition zones and areas of least use e.g. section 3, decreases as trampling intensifies and the narrow-leaved (grass) species re-colonise due to their faster recovery rate (Ikeda and Okutomi 1990, Liddle 1997). The dominance of grasses supports the finding of Roovers, Baeten, and Hermy (2004) that the species composition of a disturbed site will be dominated by the species already present before the trampling occurs in this case *Lolium perenne* and *Trifolium repens*. Summer bulk density values from across the path show a significant difference between the centre of the path and the other zones supporting hypothesis 3 that increased user levels increase soil bulk density. However, with the exception of section 1 there was no significant difference between quadrats 2 and 3, suggesting that the spread of visitors across the path in sections 2 and 3 must have been quite even. Interestingly along the length of the path the only significant decrease in bulk density in line with user levels was in section 1, with no difference recorded between sections 2 and 3. This change in the pattern of how people walk in different environments, as suggested by the bulk density and sward height, identifies an area for additional research namely focusing on the relationship between the spatial distribution of users and their environment, which would be of particular interest in the creation of new routes in Country parks for example. *Plantago major's* recognised intolerance of shade, would indicate that the use of *Plantago* as an indicator species is restricted to open areas. However in this respect the results of this study are broadly similar to those of Chappell *et al.* (1971) on chalk downlands in Dorset and Klecka (1937) in his studies in Czechoslovakia, (as reported in Liddle (1997) and would suggest that this increased cover of *Plantago* in areas of intermediate use is not site specific. This could be refined to identify if any significant relationship exists between thresholds in sward height where *Plantago* are more abundant, the soil condition and at what level of use these changes occur, over a range of different habitats. Such research might help to refine the suggestion put forward in this study that changes in *Plantago* cover provide an indirect indication of changes to soil structure by identifying changes in trampling pressure. Such a system might provide an easy and cost effective preliminary estimate of soil condition.

Management strategies for dealing with path erosion, tend to full into two basic categories; manipulating visitor behaviour away from the affected area, either physically (fencing off an area) or though persuasion education or legislation, or by strengthening the site so that it can cope with the level of use (surfacing) (Leung and Marion 2000)

With limited resources, one of the many assessments the manager must make, is whether the site is of sufficient amenity value to warrant the cost of any intervention. This cost-benefit analysis is usually based on the amenity benefit of the site against the cost of any erosion abatement work. The amenity value of a site is notoriously difficult to assess and is normally gauged by the level of use. Results from this research indicate that with nearly 20,000 visitors over the period of study (2006 to 2007) that the path is of high value to the public, indeed, Ikeringill (2007) (pers comm) suggests that the level of use is similar to that of a small country park.

It has become apparent during the course of this research that the findings can be use in two ways, one to equip the land manager with the necessary practical information on which to make a judgement, is the work need or not, secondly to justify the use of funds to higher management or public scrutiny. As suggested Leung and Marion (2000), any actual practical work is dependent on manipulating visitor away from the affected area. At private sites such as country parks, where there is an element of control over the spatial distribution of visitors this control can be physical i.e. fences or barriers, also there is less restriction on the length of time these controls can stay in place. Although public rights of way can be temporally moved or closed there are always time limits and in most cases a financial cost incurred, which must all be taken into account during any cost-benefit analysis. In general these results support the hypotheses set out in chapter 1. However, it is evident that any increase in the proportion of the *Plantago major* cover cannot be used as a direct indicator of soil compaction. Rather it represents only a direct indication of an increase in trampling, given the association between trampling (user levels) and soil compaction and there is only an indirect link between *Plantago major* and soil compaction. However, the relatively slow regrowth of *Plantago major*, when compared to the grasses makes it less effective in maintaining vegetation cover, an important requirement when trying to control erosion. A possible answer may lie in using *Plantago major* in conjunction with grasses. An increase in *Plantago major* cover is the prompt to re-seed with grasses to aid recovery of vegetation and so slow the onset of conditions in which the visible signs of erosion can take place.

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APPENDICES

Appendix I

Environmental summary data

Mean summary data across all footpath sections during summer 2007.

	User Numbers	Mean bulk density g/cm^3	*(n)*	Sward cm	Bare Ground *(%)*	*Graminae* *(%)*	*Trifolium repens* *(%)*	*Plantago spp* *(%)*
Section 1								
Quadrat 1	19,914	1.48	27	0	80.53	18.13	0.00	0.00
Quadrat 2		1.27	29	3.5	8.13	81.73	3.97	2.67
Quadrat 3		1.12	26	5.5	12.40	84.43	0.24	0.93
Quadrat 4		1.15	27	6	0.00	94.3	1.57	0.13
Section 2								
Quadrat 1	12,849	1.20	28	1.5	44.43	55.40	0.00	0.17
Quadrat 2		1.11	30	4	1.40	70.20	25.30	2.47
Quadrat 3		1.07	30	4	0.33	90.90	7.10	1.47
Quadrat 4		1.01	30	6	0.27	94.53	2.60	0.00
Section 3								
Quadrat 1	3,160	1.19	27	2	7.20	74.60	11.40	2.77
Quadrat 2		1.04	30	6.5	0.30	75.67	18.97	0.63
Quadrat 3		1.10	29	3.5	0.57	79.20	13.57	5.67
Quadrat 4		1.00	27	12	0.00	100.00	0.00	0.00

Mean summary data across all footpath sections during winter 2006/07.

	User Numbers	Mean bulk density g/cm^3	*(n)*	Sward cm	*Bare Ground* *(%)*	*Graminae* *(%)*	*Trifolium repens* *(%)*	*Plantago spp* *(%)*
Section 1								
Quadrat 1	5,458	1.43	30	0	100.00	0.00	0.00	0.00
Quadrat 2		1.17	30	3.5	63.40	36.53	0.00	0.03
Quadrat 3		1.11	30	5.5	59.97	39.60	0.13	0.17
Quadrat 4		0.99	30	4.5	25.60	73.90	0.00	0.13
Section 2								
Quadrat 1	2878	0.99	30	1.5	57.00	38.13	0.67	0.00
Quadrat 2		0.97	30	4	36.38	60.79	2.13	0.00
Quadrat 3		0.97	30	4	43.10	55.93	0.57	0.20
Quadrat 4		0.89	30	6	0.00	100.00	0.00	0.00
Section 3								
Quadrat 1	1513	1.16	30	1.5	67.00	27.97	4.90	0.03
Quadrat 2		1.11	30	6.5	40.67	55.37	2.77	0.17
Quadrat 3		1.08	30	3.5	35.53	60.13	4.07	0.17
Quadrat 4		0.99	30	12	1.87	96.33	1.47	0.00

Appendix II

Correlations between data sets

Summer data

***R* –values indicating the strength of the correlation, across all sections, between the distance of each transect from the start of the path (m), user numbers, soil bulk density g/cm^3 , bare ground, *Gramineae* cover, *Plantago spp* and *Trifolium repens*, (*n*= 90), a) = Quadrat 1, b) = quadrat 2, c) = quadrat 3 & d) = quadrat 4.**

a

	Distance (m)	*User Numbers*	*Bulk density g/cm3*	*Bare ground %*	*Gramineae %*	*Plantago spp %*	*Trifolium repens %*
Distance along the path (m)	1.000						
User Numbers	-0.941**	1.000					
Bulk density g/cm3	-0.623**	0.595**	1.000				
Bare ground %	-0.833**	0.870**	0.628**	1.000			
Gramineae %	0.725**	-0.742**	-0.625**	-0.928**	1.000		
Plantago spp %	0.447**	-0.519**	-0.040	-0.439**	0.314**	1.000	
Trifolium repens %	0.424**	-0.527**	-0.134	-0.440**	0.151	0.337**	1.000

b

	Distance (m)	*User Numbers*	*Bulk density g/cm3*	*Bare ground %*	*Gramineae %*	*Plantago spp %*	*Trifolium repens %*
Distance along the path (m)	1.000						
User Numbers	-0.941**	1.000					
Bulk density g/cm3	-0.517**	0.449**	1.000				
Bare ground %	-0.165	0.196*	0.108	1.000			
Gramineae %	0.026	0.031	-0.224*	-0.704**	1.000		
Plantago spp %	-0.288*	0.233*	0.330**	-0.100	-0.149	1.000	
Trifolium repens %	0.264*	-0.370**	0.105	-0.290*	-0.381**	0.078	1.000

c

	Distance (m)	*User Numbers*	*Bulk density g/cm3*	*Bare ground %*	*Gramineae %*	*Plantago spp %*	*Trifolium repens %*
Distance along the path (m)	1.000						
User Numbers	-0.941**	1.000					
Bulk density g/cm3	-0.134	0.058	1.000				
Bare ground %	-0.295*	0.382**	0.040	1.000			
Gramineae %	-0.160	0.138	-0.072	-0.496**	1.000		
Plantago spp %	0.385**	-0.333**	-0.016	-0.131	-0.305**	1.000	
Trifolium repens %	0.343**	-0.395**	0.036	-0.183*	-0.680**	0.079	1.000

d

	Distance (m)	*User Numbers*	*Bulk density g/cm3*	*Bare ground %*	*Gramineae %*	*Plantago spp %*	*Trifolium repens %*
Distance along the path (m)	1.000						
User Numbers	-0.941**	1.000					
Bulk density g/cm3	-0.472**	0.421**	1.000				
Bare ground %	-0.183*	0.149	-0.010	1.000			
Gramineae %	0.267*	-0.279*	-0.231*	-0.112	1.000		
Plantago spp %	-0.304*	0.246*	0.091	0.287*	-0.181*	1.000	
Trifolium repens %	-0.166	0.133	0.246*	-0.049	-0.649**	-0.055	1.000

** = significant to (P= 0.001), * = significant to (P= 0.05)

Winter data

R –values indicating the strength of the correlation, across all sections between , the distance of each transect from the start of the path (m) user numbers, soil bulk density g/cm^3 , bare ground, *Gramineae* cover, *Plantago spp* and *Trifolium repens*, (*n*= 90), a) = Quadrat 1, b) = quadrat 2, c) = quadrat 3 & d) = quadrat 4, (winter data).

a

	Distance (m)	*User Numbers*	*Bulk density g/cm3*	*Bare ground %*	*Gramineae %*	*Plantago spp %*	*Trifolium repens %*
Distance along the path (m)	1.000						
User Numbers	-0.916**	1.000					
Bulk density g/cm3	-0.480**	0.564**	1.000				
Bare ground %	-0.429**	0.515**	0.523**	1.000			
Gramineae %	0.399**	-0.482**	-0.519**	-0.912**	1.000		
Plantago spp %	0.089	-0.115	0.000	-0.183*	0.208*	1.000	
Trifolium repens %	0.293*	-0.275*	-0.014	-0.237*	0.031	-0.030	1.000

b

	Distance (m)	*User Numbers*	*Bulk density g/cm3*	*Bare ground %*	*Gramineae %*	*Plantago spp %*	*Trifolium repens %*
Distance along the path (m)	1.000						
User Numbers	-0.916**	1.000					
Bulk density g/cm3	-0.160	0.175	1.000				
Bare ground %	-0.345**	0.378**	0.053	1.000			
Gramineae %	0.291*	-0.327**	-0.030	-0.969**	1.000		
Plantago spp %	0.055	0.002	-0.023	0.190*	-0.185	1.000	
Trifolium repens %	0.235*	-0.246**	-0.095	-0.072	0.032	0.023	1.000

c

	Distance (m)	*User Numbers*	*Bulk density g/cm3*	*Bare ground %*	*Gramineae %*	*Plantago spp %*	*Trifolium repens %*
Distance along the path (m)	1.000						
User Numbers	-0.916**	1.000					
Bulk density g/cm3	-0.051	0.115	1.000				
Bare ground %	-0.372**	0.371**	0.294*	1.000			
Gramineae %	0.333**	-0.329**	-0.296*	-0.985**	1.000		
Plantago spp %	0.034	-0.005	-0.062	-0.165	0.153	1.000	
Trifolium repens %	0.284*	-0.308*	-0.022	-0.238*	0.070	-0.017	1.000

d

	Distance (m)	*User Numbers*	*Bulk density g/cm3*	*Bare ground %*	*Gramineae %*	*Plantago spp %*	*Trifolium repens %*
Distance along the path (m)	1.000						
User Numbers	-0.916**	1.000					
Bulk density g/cm3	-0.106	0.059	1.000				
Bare ground %	-0.479**	0.523**	0.076	1.000			
Gramineae %	0.440**	-0.486**	-0.077	-0.978**	1.000		
Plantago spp %	-0.124	0.141	-0.058	0.020	-0.061	1.000	
Trifolium repens %	0.140	-0.134	0.050	0.049	-0.242*	-0.013	1.000

** = significant to (P= 0.001), * = significant to (P= 0.05).